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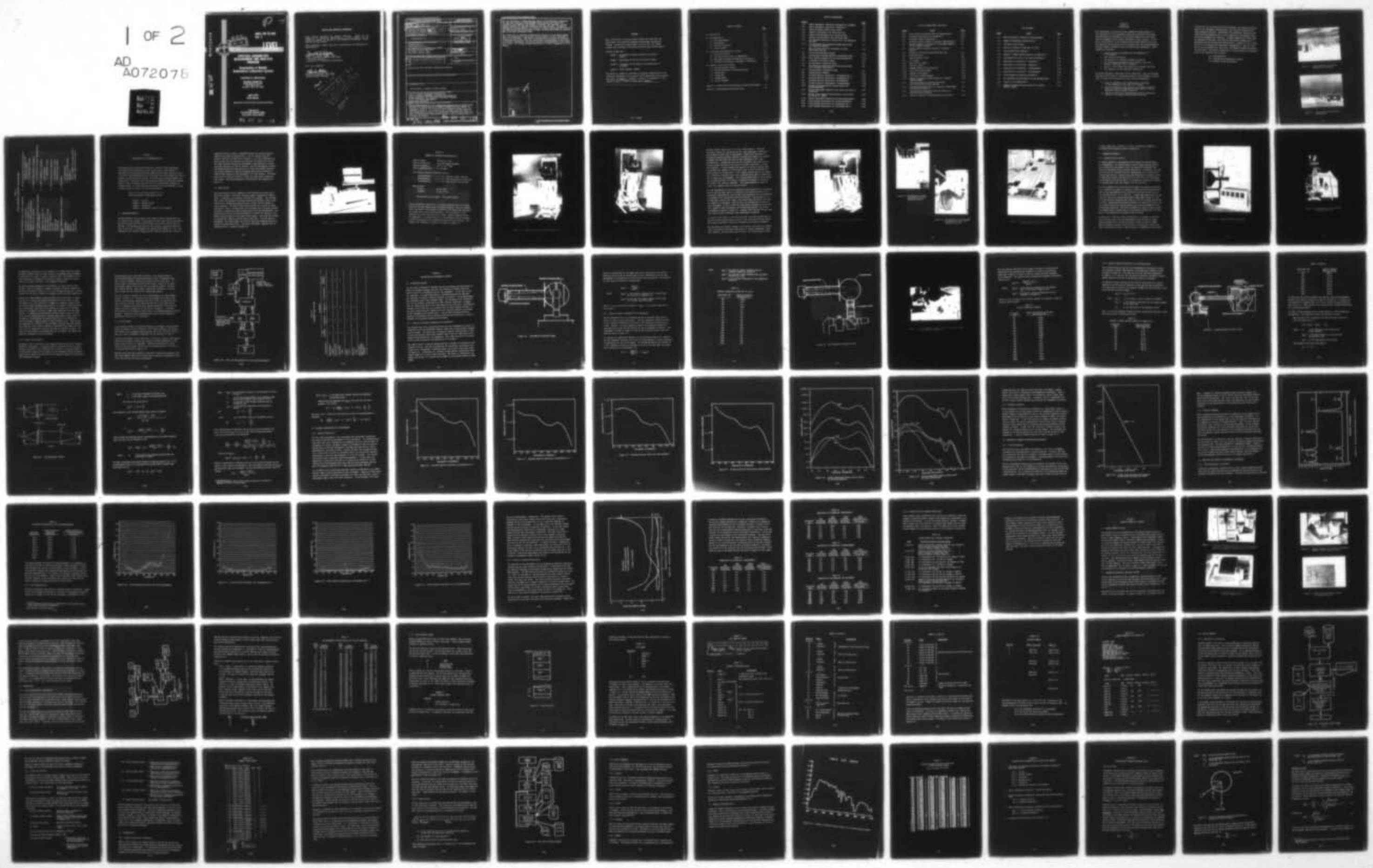

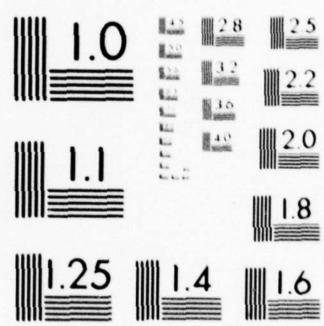

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AWS/TN-79/001
Vol. I

LEVEL II

AIR WEATHER SERVICE

SPECTRAL RADIOMETRIC MEASUREMENT AND ANALYSIS PROGRAM

Description of Mobile Radiometric Laboratory System

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Rochester, New York 14650

April 1979
Final Report

Approved for Public Release; Distribution Unlimited

Prepared for
AIR WEATHER SERVICE (MAC)
Scott AFB, Illinois 62225

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IN SITU ATMOSPHERIC MEASUREMENTS
GROUND-BASED RADIOMETRY

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report covers a ~~Eastman Kodak Company~~ recently completed ~~a~~ contract with the United States Air Force Air Weather Service to conduct research into the transfer of atmospheric energy in the visible and near-infrared portions of the electromagnetic spectrum. Its objective was to produce a spectral model of path transmittance, radiance, and ground-level irradiance that could be related to meteorological observations through the use of simultaneous, in-situ data collections. CONT

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For data collection, a self-sustaining, mobile, field radiometric laboratory was used that contained custom-designed spectroradiometers, mechanical/electrical servo controls, and computer interfaces; the laboratory utilized computer software for laboratory operation and data analysis. By means of minicomputers and peripherals, the laboratory produced calibrated and corrected data that could later be processed on larger, in-house IBM systems for development of the final radiometric model.

This volume (No. 1) provides an engineering description of the mobile laboratory, the calibration of radiometers, and the computer software developed to operate the laboratory. More detailed documentation of devices and software is available upon request that will permit better understanding of the details of electronic, mechanical, and optical operation and maintenance of the laboratory system. This related system documentation is listed in Appendix A of this volume.

FOREWORD

This is the first in a series of four volumes that constitute the final report on the Spectral Radiometric Measurement and Analysis Program. To make this lengthy report easier to use, each volume contains only information concerning a specific phase of the project.

The four volumes are:

Volume 1: Description of Mobile Radiometric Laboratory System

Volume 2: Description of the Data Collection Program

Volume 3: Discussion of Data Analysis and Formulation of the Model

Volume 4: SCAT3 Operator's Manual.

The effort by a number of individuals contributed significantly to the successful completion of this project and the publication of this report. They were: R. Simmons, G. Schauss, R. Norton, R. Schoenfeld, G. Van-Arsdale, M. Nier, N. Lurie, C. Vogt, and J. Johnson.

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SECTION I
INTRODUCTION

This development of a state-of-the-art atmospheric model based on on-site observations of the radiometric quantities necessitated the design and fabrication of a radiometer system having capabilities well beyond those of equipment used on similar experiments in past projects. At the start of this effort, it was recognized that certain capabilities of the data gathering system would have to be designed into the spectroradiometers and their support systems in order to fulfill these requirements. These capabilities included:

a. Complete spectral measurement from 350 nanometers to 1.2 micrometers.

b. Real-time data processing.

c. Semi-automatic or completely automatic operation.

d. The simultaneous measurement of sky radiance, path transmittance, and ground level irradiances.

e. Mobility, with minimum time required for breakdown and setup.

f. The capability for meteorological observation.

The Mobile Radiometric Measurement System (laboratory), which was designed and fabricated by EG&G Inc, Albuquerque Division, was developed in a mobile form to provide the following three basic spectral measurements:

(1) Spectral atmospheric path transmittance as estimated by the attenuation of the solar disc radiance.

(2) Spectral atmospheric path radiance as estimated by measurement of the spectral radiance of a fixed region of the sky hemisphere and its angular dependence.

(3) Spectral irradiance on surfaces having various orientations relative to the azimuth and elevation of the sun.

To facilitate the recording of near-instantaneous, high-resolution spectra from several instruments simultaneously, the system was fabricated for fully automated operation. The hardware and electronics, which were centered around minicomputer control, were custom-built and represent state-of-the-art equipment and technology. To permit sampling of a broad range of atmospheric conditions, the system was made mobile through use of a customized trailer and dedicated towing vehicle. Figures 1-1 and 1-2 show the van in its transport and operational configurations. Table 1-1 summarizes the instrumentation, electronics, and support systems that make up the laboratory. The detailed capabilities of the laboratory are described below in the following three sections:

2.0 Instrumentation

3.0 Calibration and Radiometric Accuracy

4.0 Computer System and Software.

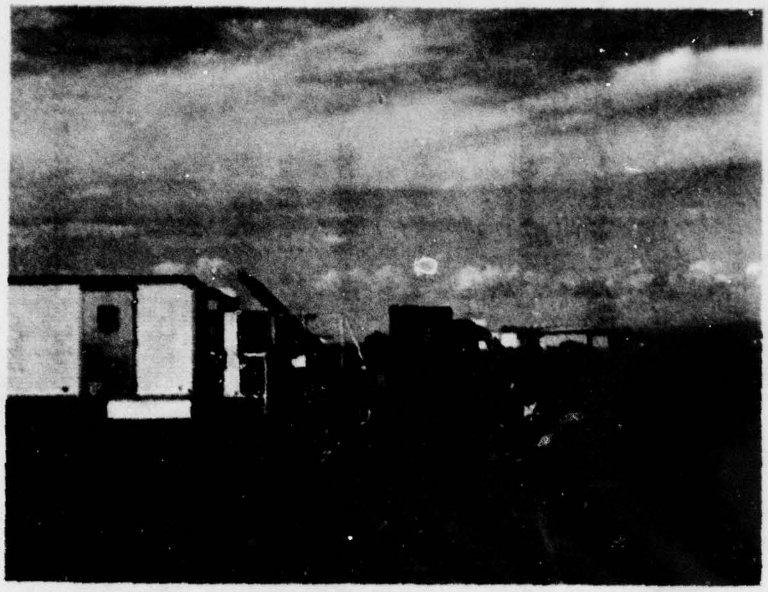

Figure 1-1. Mobile Radiometric Laboratory Configured for Transport

Figure 1-2. Mobile Radiometric Laboratory in Operation

TABLE 1-1

MOBILE RADIOMETRIC LABORATORY SYSTEM EQUIPMENT

1. Four Spectroradiometers and a Utility Radiometer:
   - Two pointable irradiometers
   - Pointable sky radiometer (W/T.V.)
   - Equatorially mounted transmissometer
   - Tethered utility radiometer

2. Components of Data Processing System for Instrument Operation and Data Handling:
   - Standard data terminal I/O
   - Graphics display I/O
   - Mag tape cassette recorders
   - Paper tape read/punch
   - Disc file
   - Hard copy unit
   - 32K CPU core

3. Meteorlogical Measuring Instruments (mounted on a 10m tower):
   - Temperature
   - Pressure
   - Humidity
   - Wind speed
   - Wind direction

4. On-Board Radiometric Calibration Devices:
   - Radiance and irradiance NBS-traceable standards
   - Line wavelength standards

5. On-Board Power Generation Equipment:
   - Two electrically isolated 15KW generators

6. On-Board Communication Equipment:
   - Radio-telephone
   - C.B. Radio/walkie-talkie

7. Mobile Trailer System Components:
   - Dual tandem-axle trailer
   - Dedicated towing vehicle

8. Conveniences:
   - Air conditioning
   - Hot and cold bottled water
   - Refrigerator
   - Office equipment and storage cabinets
   - Overhead lighting and wall service

SECTION 2
DESCRIPTION OF THE INSTRUMENTATION

The laboratory was constructed around four identical spectroradiometers that differ only with respect to their input optics. Each utilizes a six-position filter wheel containing order-sorting filters located in front of a Jarrall-Ash monochromator that is attached to an EG&G thermo-electrically cooled, 585 photomultiplier system. The filter wheel and monochromator are controlled by closed-loop servo systems and are driven by precision stepping motors. These instruments and their role in the measurement program are outlined below. If a more detailed description of each instrument is needed, reference should be made to the following documents:

Operations and Maintenance Manuals for the
Mobile Radiometric Measurements System:

Volume 1: Optical
Volume 2: Weather System
Volume 5: Mechanical
Volume 6: Radiometric Analysis of Instruments

2.1 SPECTRORADIOMETERS

The monochromators are designed to the symmetric Ebert configuration with a 0.25-meter focal length. Two gratings are used, both ruled to 590 grooves/mm; one is blazed for first-order diffraction at 400 nm, and the other at 1000 nm. The fixed entrance and exit slits result in spectral resolution that is very near 5 nm throughout the spectrum from 350 nm to 1.2 μm. The radiometers are standard, high-sensitivity EG&G 585 systems that consist of

thermoelectrically cooled S-1 photomultipliers with external voltage supplies and cooling controller units. The S-1 response provides spectral sensitivity from 350 nm to beyond 1.1 μm, thus eliminating the need for more than one detector to cover both the visible and near IR. The signal monitored during the measurement is photomultiplier current digitally displayed on a 580-13 indicator that has autoranging circuitry. The photomultiplier has been shown to be linear with radiant intensity over several decades of response throughout the spectral sensitivity range of these detectors (see paragraph 3.2 of this volume). The radiometer system is shown in Figure 2-1, where the input-optics connection can be seen. The spectroradiometer characteristics are summarized in Table 2-1.

2.2 INPUT OPTICS

The unique aspect of each radiometer is the design of the input optics, which was tailored to the three necessary types of radiometric measurements: irradiance, sky radiance, and solar disc radiance. The irradiometer optics are gimballed to permit elevation and azimuth rotation, and consist of an integrating sphere that has a clear, sharply defined entrance aperture. An optical train, which consists of a series of lenses and mirrors, views a constant region of the sphere wall and passes uniform, incoherent, nonpolarized radiant energy down to the spectroradiometer. The gimbaled optics can be rotated 360 degrees in azimuth, 90 degrees in elevation, and positioned to the nearest whole degree. Less than five seconds is required for complete rotation about either axis. Like the spectroradiometers, the input optics are driven by precision stepping motors controlled by closed-loop servos. The entire instrument, complete with its controller unit, is shown in Figure 2-2.

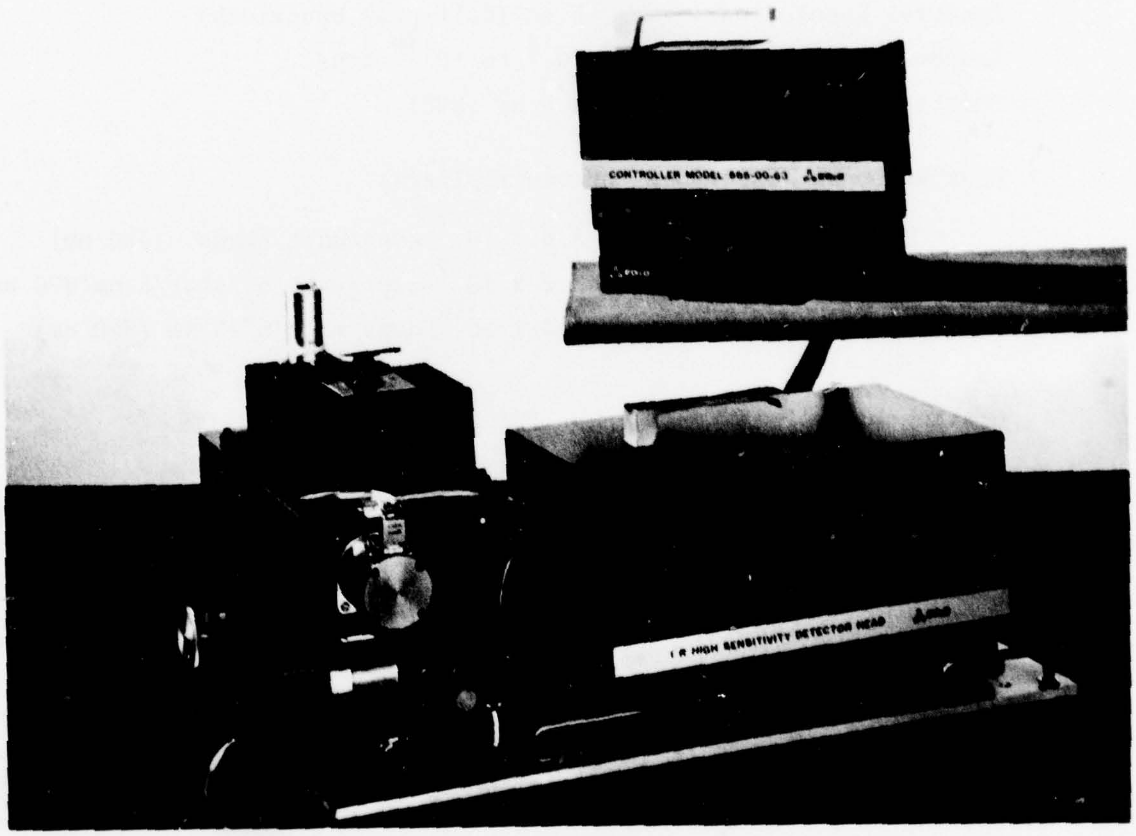

Figure 2-1. Spectroradiometer Without Input Optics

TABLE 2-1

SUMMARY OF RADIOMETER CHARACTERISTICS

Spectral Range:	350 nm to 1.2 μm
Spectral Resolution:	5 nm (half-peak bandwidth)
Response Linearity:	10^{-5} to 10^{-10} amps
Spectral Repeatability:	1.5 nm (RMS)
Peak Response (Using S-1 Photomultipliers):	
Transmissometer:	3.6×10^{-7} amps/unit trans. (350 nm)
Sky Radiometer:	3.2×10^{-7} amps/watt/m^2/ster/5 nm(470 nm)
Irradiometer(s):	1.4×10^{-6} amps/watt/m^2/5 nm (350 nm)
Grating Blaze:	
Visible:	400 nm (68°)
Infrared:	1.0 μm (17.2°)
Monochromator Focal Length:	0.25 meters (*f*/3.5)

The sky radiometer consists of a 0.15-meter telescope with a 15-degree field of view that feeds a small integrating sphere. Like the irradiometers, the optical train samples a portion of the sphere wall and passes the energy down to the spectroradiometer. This instrument is also gimballed in azimuth and elevation to permit complete sampling of the sky hemisphere. A closed-circuit TV is also mounted with the telescope to permit monitoring of sky conditions from the trailer interior. The complete sky radiometer is shown on its mount in Figure 2-3.

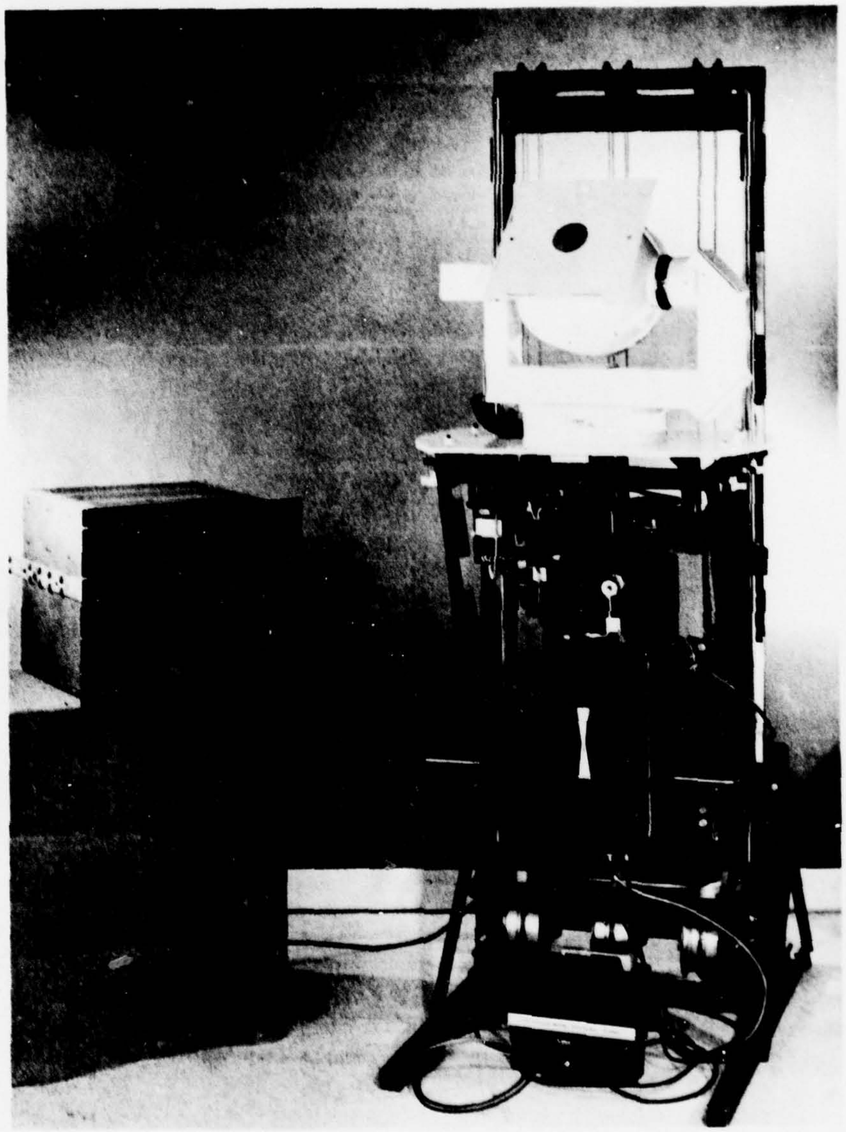

Figure 2-2. Complete Irradiometer With Controller Unit

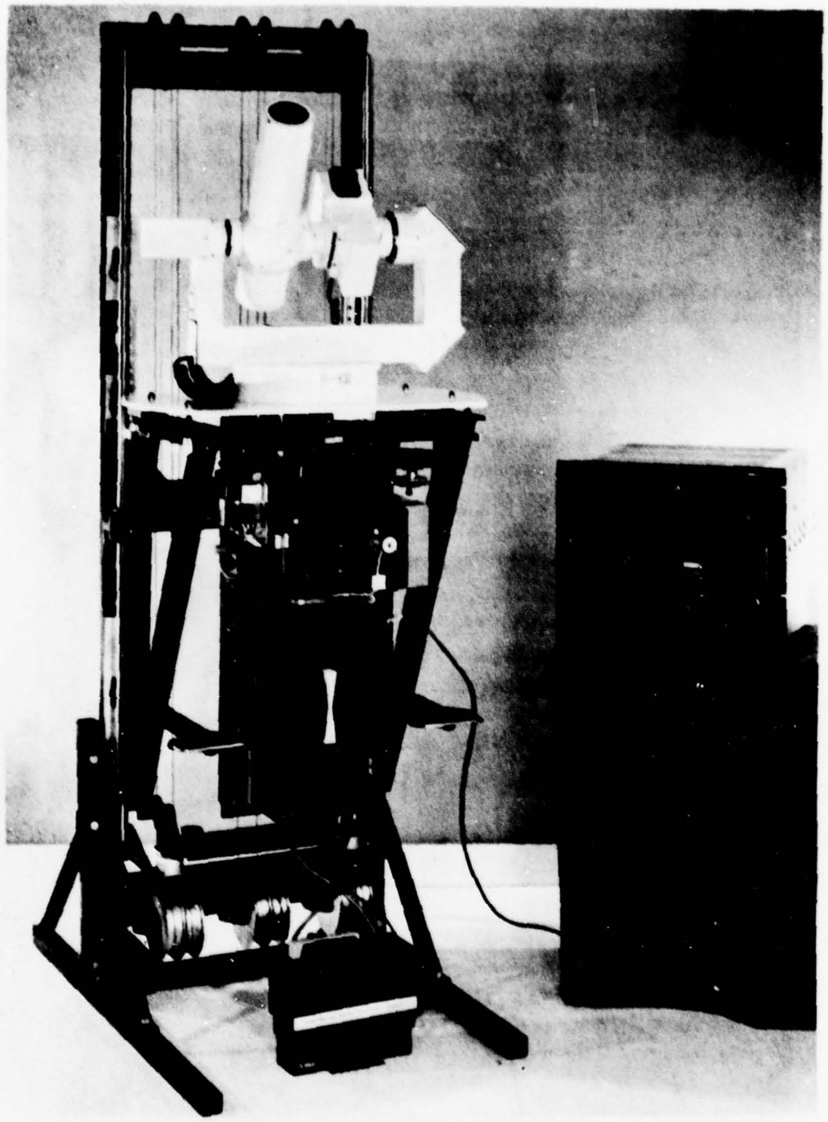

Figure 2-3. Complete Sky Radiometer With Controller Unit

The most complex input optics is for the transmissometer. This unit continually tracks the sun during the day, thus requiring an equatorial mount similar to that used by astronomers. Because the instrument is mounted on a mobile platform, degrees of freedom are required for azimuth alignment with the north pole and latitude adjustment of the right-ascension axis. Leveling devices are also included on the input optics; however, proper leveling of the trailer is usually sufficient to insure good tracking. A second imaging tube parallel to the main sampling tube is provided that produces a signal proportional to both declination and right-ascension tracking errors. These signals control servos that change the declination elevation and/or right ascension drive speed to compensate for the solar disc misalignment. The transmissometer does not have azimuth and elevation controls as the other instruments do because its pointing direction is not operator-commanded. The transmissometer is shown in Figure 2-4, complete with its controller unit.

The four radiometers are all wall-mounted on slide rails inside the trailer. Because only the input optics are exposed to the trailer exterior in the operational configuration, the detectors and electronics are environmentally conditioned by air conditioning inside the trailer. The radiometers, including their related input optics, are stored below the trailer roof when the system is in transport. When on-site, the radiometers are raised as shown in Figures 2-5 and 2-6 with the input optics extended above the roof line. When all four instruments are in operating position, the trailer roof appears as shown in Figure 2-7. Catwalks cover the roof and give operators access to the instruments when maintenance is required.

As a part of the system, it was also necessary to design and fabricate an on-board surface meteorological system so that continuous surface weather data would be provided to which the radiometric data could be compared.

The on-board meteorological package is positioned at the top of a 10-meter tower and provides simultaneous monitoring of surface temperature, pressure, humidity, and wind speed and direction. The meteorological system

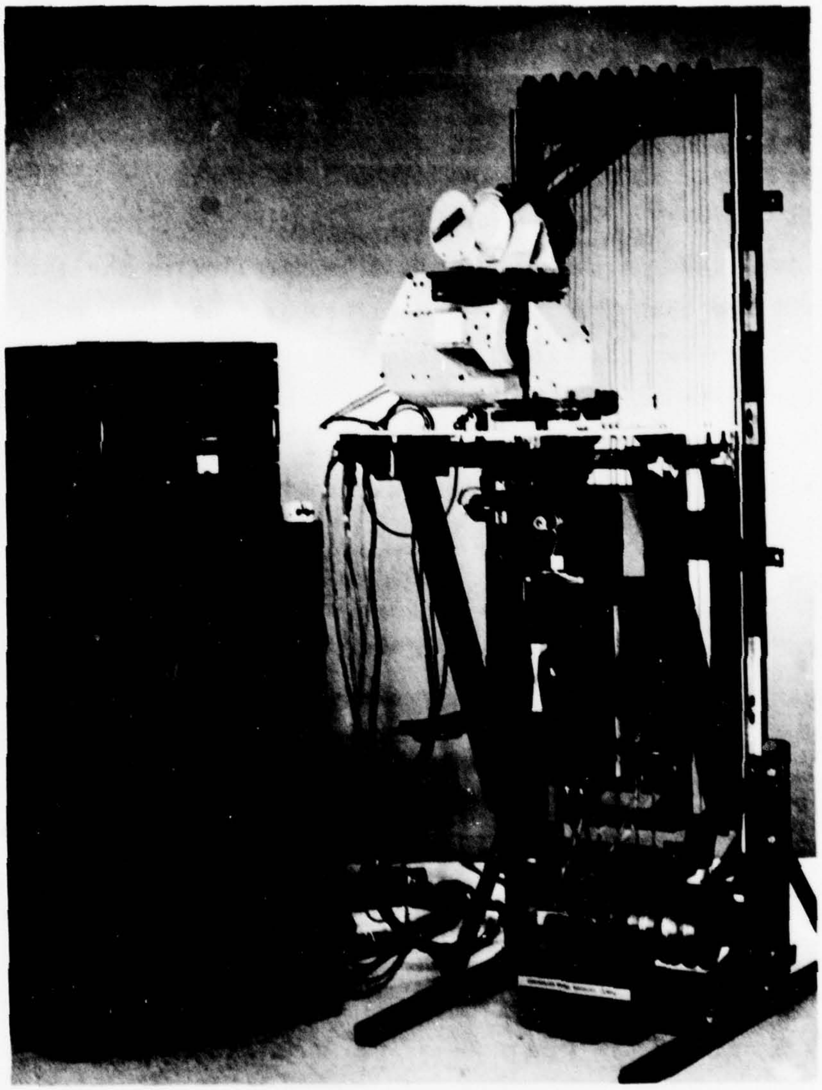

Figure 2-4. Complete Transmissometer With Controller Unit

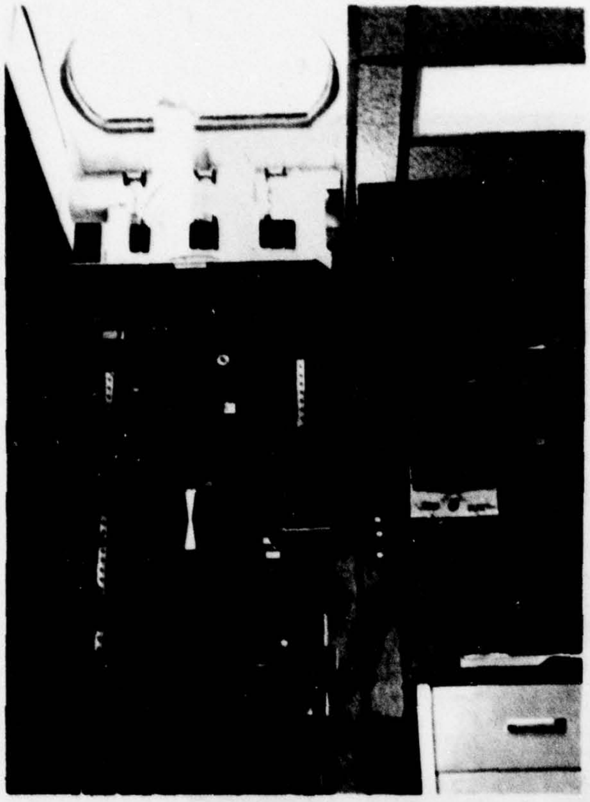

Figure 2-5. Sky Radiometer Mounted in Trailer and in Its Retracted Position

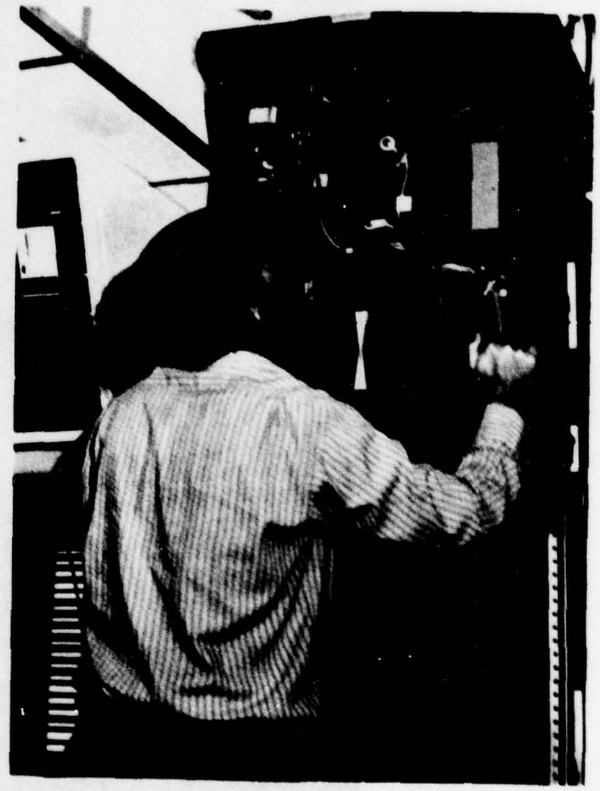

Figure 2-6. Sky Radiometer Being Extended Through Trailer Roof into Operating Position

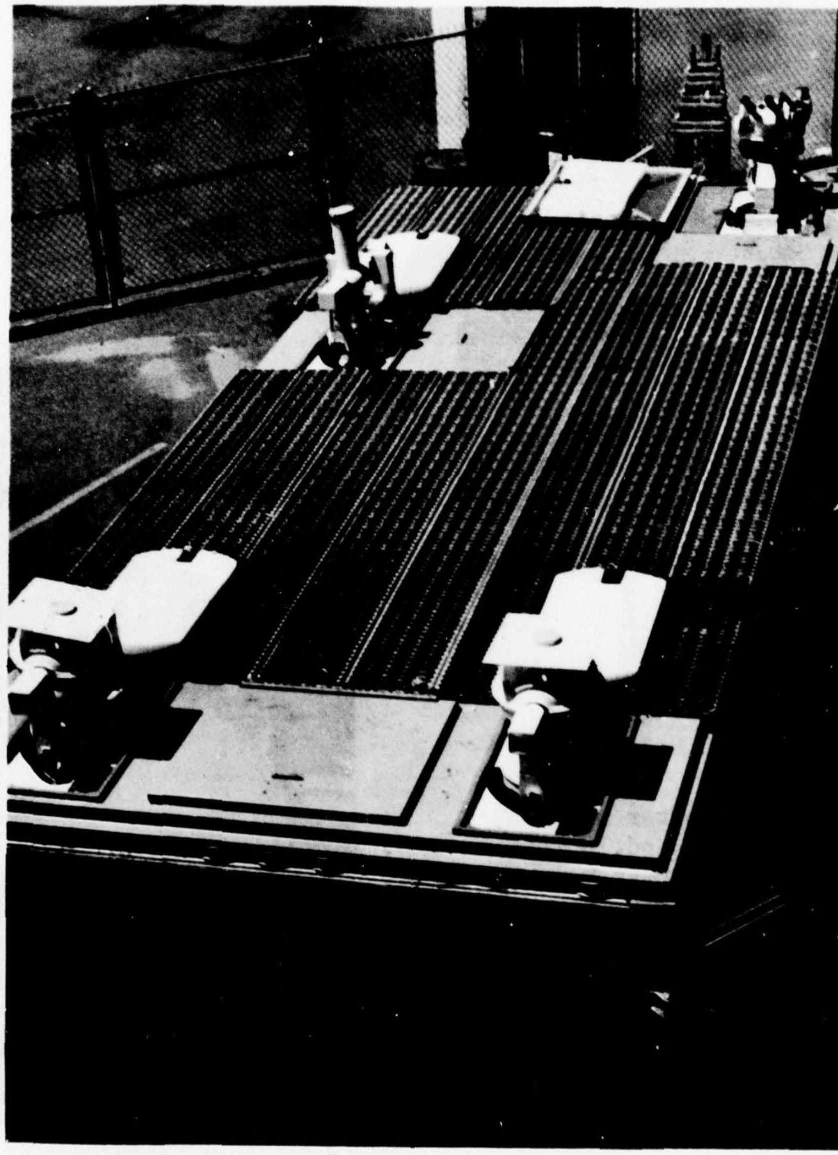

Figure 2-7. Roof of Trailer With All Instruments
in Their Operational Position

is shown stowed away in Figure 2-8, and in its mounted configuration elevated on the collapsible tower in Figure 2-9.

2.3 ON-BOARD ELECTRONICS

2.3.1 Positional Servo Devices

The Mobile Radiometric Measurement System includes one sky radiometer, two irradiometers, one transmissometer, and one spare spectroradiometer. Each of these five instruments can be electronically controlled with respect to wavelength filter position and grating. In addition, the input optics to the sky radiometer and the irradiometers can be controlled in azimuth and elevation. Control is accomplished manually through a series of thumb wheel switches and push buttons on the front of the instrument control chassis (for the set mode) or automatically through the interface Data General Super Nova-1200 computer (for the CPU mode).

With the exception of the selection of gratings, all mechanical functions (e.g., position in azimuth or elevation, rotation of the wavelength drive shaft on the monochromators, and rotation of the filter wheel) are controlled electronically in the same way. In each case, motive power is provided by a precision stepping motor whose output shaft rotates at either 0.75° per step for wavelength and filter or 0.36° per step for azimuth and elevation. Because gearing reduces the motion per step still further, the drive shaft involved in a given function can be moved incrementally with the necessary precision. The motor is driven by a train of current pulses that permit either a single step or an essentially endless train of steps, and it is instantaneously reversible within one step.

In each case, a precision linear potentiometer is included in the drive train with the result that the potentiometer turns through its range. The potentiometer has a stable dc potential across it, and its output feeds an analog-to-digital converter that is electronically tied to the motor control/drive circuits. When the motor is commanded to turn (either

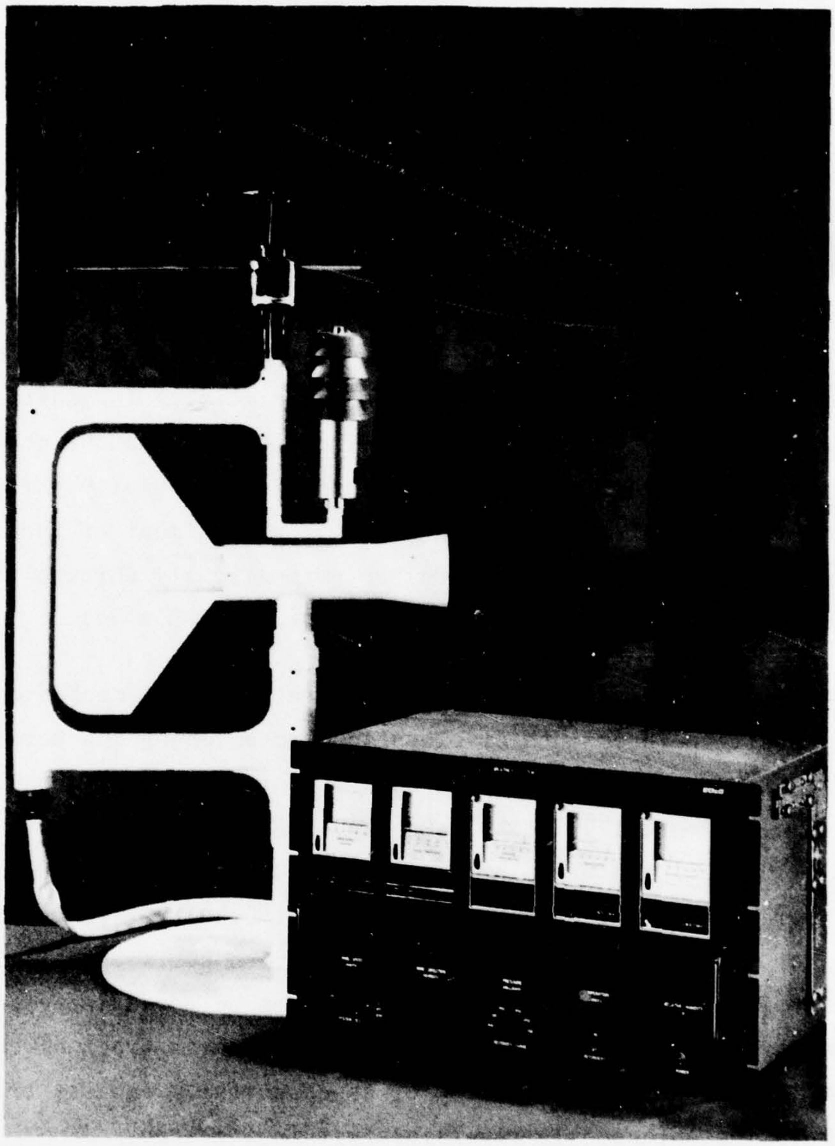

Figure 2-8. On-Board Meteorological System

Figure 2-9. Meteorological Package Mounted on Retractable Tower

by thumb wheel switches or by the computer), it rotates until the analog-to-digital computer digital output equals the programmed digital command, at which point it stops. Accuracy is within 1 bit. This method of operation eliminates the sources of instability normally present in closed-loop servo systems, and there is no overshoot or hunting.

The grating-change mechanism is controlled by a dc motor and two micro-switches. When the command to change is received, the motor rotates the grating from whichever position it is in to the opposite position, and then reverses for 100 msec to remove all pressure from the grating change lever.

Because the transmissometer tracks the solar disc continuously, it therefore does not require the azimuth and elevation controls that the other instruments have. The solar disc is imaged on a quadrant detector diode that produces photo currents proportional to the amount of image falling on any one quadrant. These four diode currents are converted to voltages, amplified, and added to provide a signal that represents the total diode current. In addition, the difference in signals from the pair of vertically oriented diodes was taken to obtain a declination signal error; in the same way, the difference in signals from the pair of horizontally oriented diodes is taken to obtain a right-ascension error. These errors are compared with a portion of the sun signal, and when the error exceeds this reference level, digital commands are generated that enable the drive circuit of the appropriate motor and indicate the direction to move. Because the error signals are compared with the sun signal, the digital commands are independent of solar intensity.

2.3.2 Digital Data Channels

Radiometric data is available to the computer from each of the five spectroradiometric instruments. An analog current is developed by the S-1 photomultiplier mounted on each instrument and converted to a digital signal by the EG&G 580-13 Indicator Unit mounted in the Instrument Controller Chassis. These digital signals are interfaced to the computer through the Data General 5602 Input/Output Chassis.

Meteorological data is also made available to the computer from an on-board meteorological system that monitors surface temperature, pressure, relative humidity, and the speed and direction of the wind. An analog signal is developed by each of the sensors located at the top of the 10-meter tower; they are converted to a digital signal by the EG&G AML-2 Weather System. These digital signals are interfaced to the computer through the Data General 5602 Input/Output Chassis.

The servo and data channels for the spectroradiometers are shown schematically in Figure 2-10. The position in/out channels are actually five channels corresponding to grating angle drive, order sorting filter position, grating selection, and azimuth and elevation of the input optics. Table 2-2 summarizes the binary coded decimal channels for the four permenantly installed radiometers and the utility radiometer. A detailed description of the electronics can be found in the EG&G/Albuquerque Division document: Operations and Maintenance Manual for the Mobile Radiometric Measurements System, Vol 3: Electrical.

2.4 TRAILER SYSTEM

As was indicated above, the spectroradiometers, electronics, and associated optics are housed in a 20 ft trailer. This trailer provides a controlled environment for the photomultiplier detector units and a facility similar to that of a typical radiometric laboratory for the operators to work in.

The power requirement for the laboratory is 208 volts, 40 amps, three phases, which can be supplied either by the on-board twin Onan generators or from facility power, when it is available. External connections for either source can easily be made. One of the two on-board generators is shown in its installed position in Figure 2-11.

Gasoline tanks that were attached to the trailer supplied the generator with fuel, and transfer tanks on the towing vehicle permitted the generator tanks to be refilled while the unit was deployed.

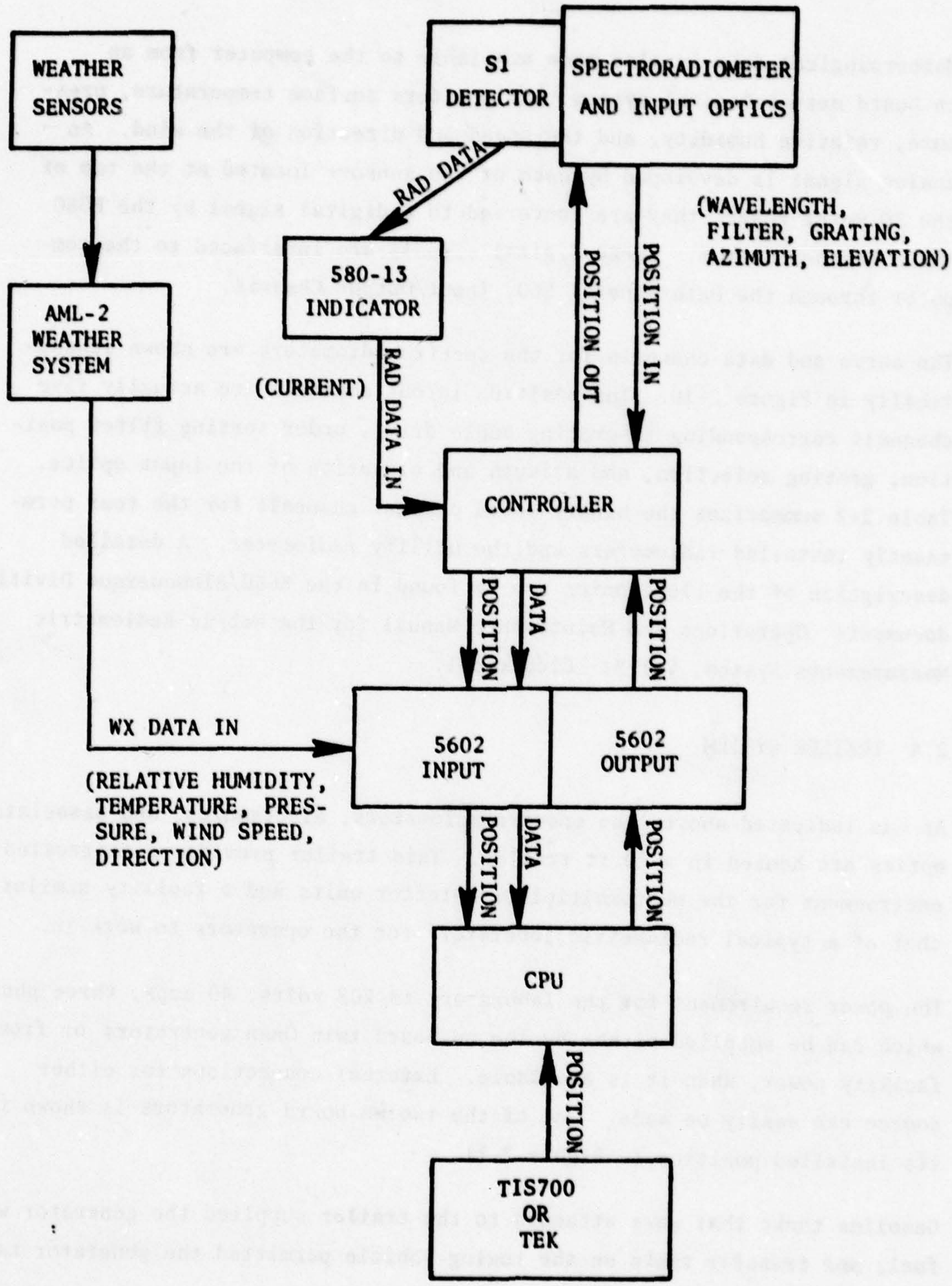

Figure 2-10. Servo and Data Channels for the Spectroradiometers

TABLE 2-2

INSTRUMENT SERVO SYSTEMS

Servo Drives:	INSTRUMENTS				
	Sky Radiometer	Irradiometer No. 1	Irradiometer No. 2	Transmissometer	Utility Radiometer
Monochromator 10-Bit	X	X	X	X	X
Grating Select	X	X	X	X	X
Filter Wheel 8-Bit	X	X	X	X	X
Azimuth 10-Bit	X	X	X		
Elevation 8-Bit	X	X	X		
Closed-Loop Solar Tracking Servo System (Analog)				X	

SECTION 3

CALIBRATION AND RADIOMETRIC ACCURACY

3.1 CALIBRATION DEVICES

For this effort radiometric standards for each instrument were maintained on-board, and tungsten-halogen, 200-watt, NBS-traceable, standard lamps were used for both the irradiometers and the sky radiometer. In the case of the sky radiometer, an integrating sphere is introduced between the lamp and the telescope to produce a uniform reference of radiance. The transmissometer was calibrated using ribbon filament lamps. The radiance of the central portion of the filament, calibrated by an NBS-traceable laboratory, is imaged onto the sampling aperture in the same manner as the solar disc. Ratioing the radiance of the solar disc, as estimated from the lamp filament radiance, to the known extraterrestrial radiance (or solar constant) produces an estimate of the atmospheric path transmittance. The on-board calibration devices, methods of calibration, and the equations used are described below, as well as estimates of calibration precision and accuracy.

3.1.1 Spectral Irradiance Standard for Irradiometers

The standard used in the calibration device for the irradiometers consists of commercial GE-type Q6.6A/T4Q/ICL 200-watt lamps with a quartz-halogen tungsten coiled filament. The lamps were calibrated by Optronic Laboratories by transferring calibrations from an NBS standard lamp to the test lamp using a wavelength-by-wavelength method of comparison. Both lamps were set at a distance of 50 cm from the detector and operated at a set current.

The lamp is used in a special housing that has a filament-to-housing exit port distance of 50 cm. When the irradiometers are calibrated, the housing is attached to the irradiometer integrating sphere input port in the manner shown in Figure 3-1. A precision, dc, constant-current Optronic Laboratories Power Source, Model 65, is used to power the lamp. The source is calibrated to an output of 6.50 amp ± 0.1 percent and traceable to the National Bureau of Standards.

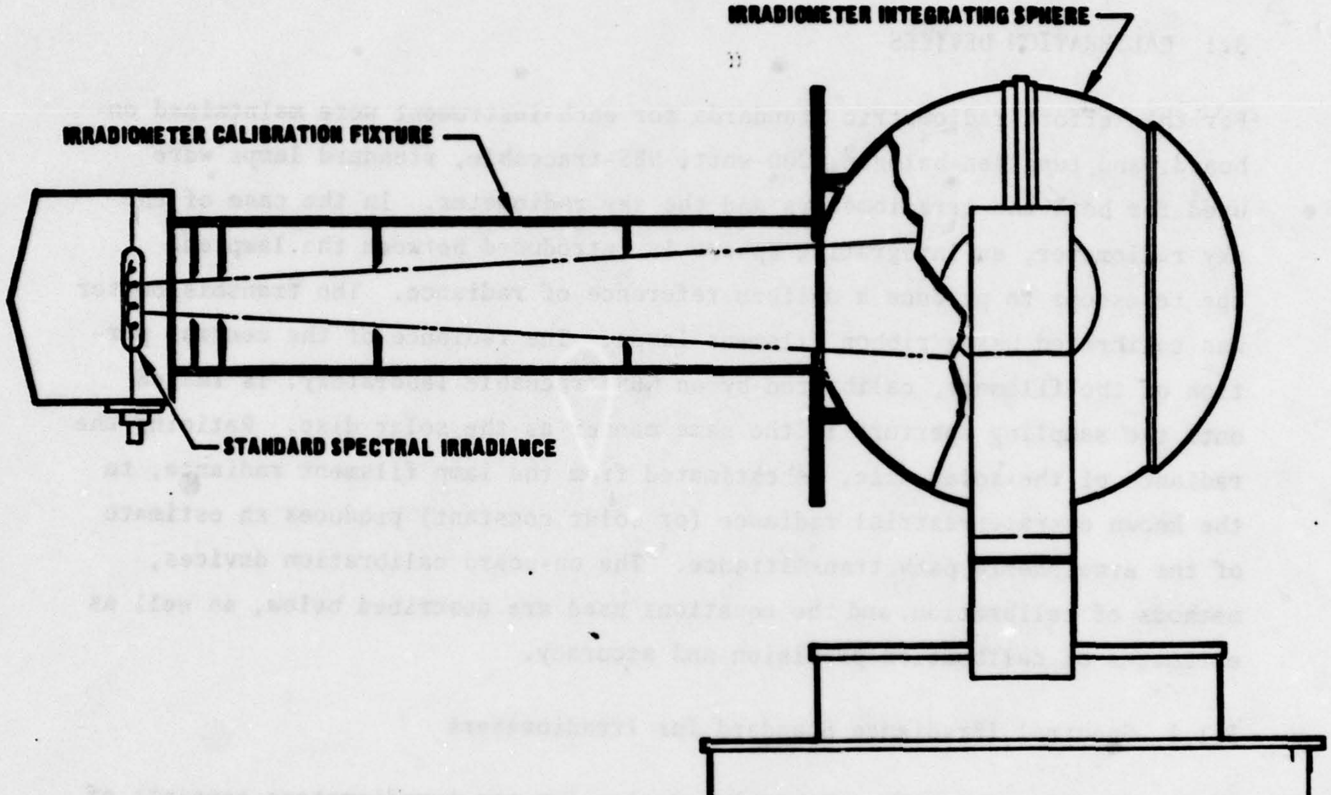

Figure 3-1. Irradiometer Calibration Setup

Since the calibrations for the lamps used in the field were at the correct operating distance and the entrance port of the irradiometers was the limiting aperture, no manipulation of the original data was required. The equation for the spectral calibration constants was:

$$K_{IRR}(\lambda) = \frac{H_{STD}(\lambda)}{A_{IRR}(\lambda)}$$

Where: $H_{STD}(\lambda)$ is the spectral irradiance of a standard lamp at 50 cm and 6.5 amperes, and

$A_{IRR}(\lambda)$ is the spectral current reading of PMT output for standard lamp measurement.

Table 3-1 lists the spectral irradiance, $H_{STD}(\lambda)$, of a typical lamp used in this project.

3.1.2 Spectral Radiance Standard for Sky Radiometer

The sky radiometer had to be calibrated against an extended source and in units of energy per unit solid angle. The same calibration fixture was used in this radiance calibration as was used in the irradiance calibration procedure. However, a 12-inch integration sphere was introduced between the lamp housing exit port and the entrance to the sky radiometer telescope. This arrangement is shown in Figure 3-2, and the device being fitted to the telescope is shown in Figure 3-3.

To calculate the sphere-wall radiance for the calibration device as viewed by the sky radiometer telescope, the ratio of exiting radiance to input irradiance was determined for the 12-inch sphere. By referencing against the radiance of a flat, lambertian reflector irradiated at 50 cm by the same lamp, the sphere wall "efficiency" was determined to be:

$$\rho(\lambda) = \frac{A_{REF}(\lambda)}{A_{SPH}(\lambda)} \times R_{REF}(\lambda)$$

Where: $A_{REF}(\lambda)$ are spectral current readings from the reference lambertian reflector,

$A_{SPH}(\lambda)$ are spectral current readings from the sphere interior wall, and

$R_{REF}(\lambda)$ is the spectral reflectance of the lambertian reflector.

TABLE 3-1

SPECTRAL IRRADIANCE OF LAMP M147 AT 50 CM

Wavelength (nm)	Spectral Irradiance (Watts/M^2/5 nm
350	.00783
400	.0215
450	.0437
500	.0730
550	.106
600	.138
650	.167
700	.192
750	.210
800	.221
850	.229
900	.233
950	.232
1000	.227
1050	.221
1100	.214
1150	.205
1200	.194

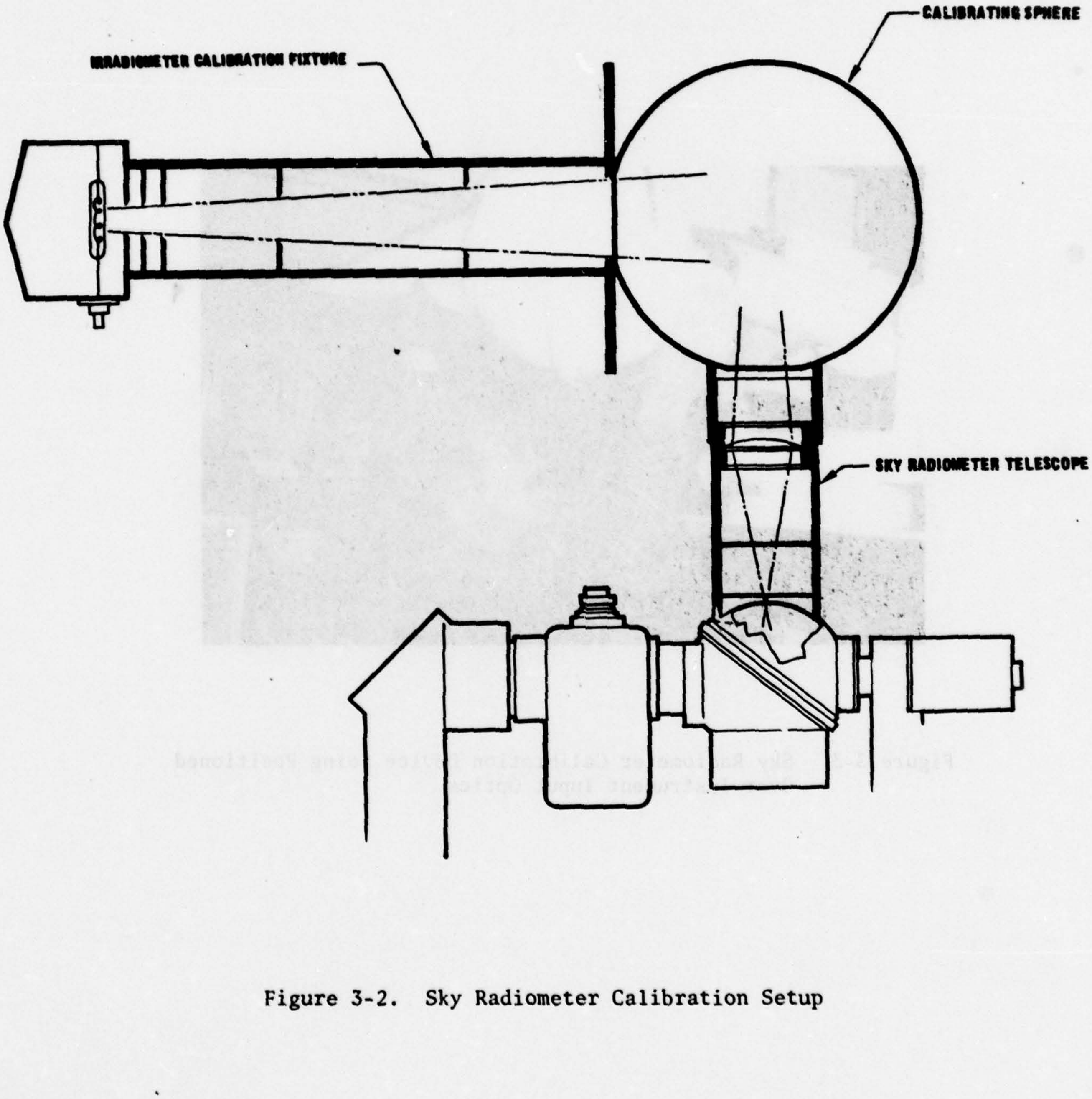

Figure 3-2. Sky Radiometer Calibration Setup

Figure 3-3. Sky Radiometer Calibration Device Being Positioned Over Instrument Input Optics

Once the spectral efficiency of the sphere was known, it could then be multiplied by the spectral lamp irradiance to arrive at the spectral sphere wall radiance in terms of watts per square meter per steradian per 5 nanometers. The equation used to produce the radiometer calibration constants was:

$$K_{SKY}(\lambda) = \frac{H_{STD}(\lambda) \cdot \rho(\lambda)}{A_{SKY}(\lambda)}$$

Where: $H_{STD}(\lambda)$ **is the spectral irradiance of the standard lamp at 50 cm and 6.5 amperes, and**

$A_{SKY}(\lambda)$ **are spectral current readings from the sky radiometer calibrations.**

Table 3-2 lists the sphere wall spectral radiance for lamp M147, which was typically used on-board.

TABLE 3-2

TYPICAL SPHERE WALL RADIANCE

Wavelength (nm)	Sphere Wall Radiance Using M147 (W/M^2/ster/5 nm)
350	**.00036**
400	**.00101**
450	**.00240**
500	**.00404**
550	**.00584**
600	**.00737**
650	**.00868**
700	**.00980**
750	**.0107**
800	**.0112**
850	**.0115**
900	**.0116**
950	**.0115**
1000	**.0111**
1050	**.0112**
1100	**.0105**
1150	**.00952**

3.1.3 Spectral Radiance Standard for the Transmissometer

The calibration device used for the transmissometer consisted of a spectral radiance standard lamp mounted in a housing with a parabolic mirror as shown in Figure 3-4. The lamp was a GE type 30A/T24/3 operating at 35 amps dc (± 0.1 percent) and calibrated by Optronic Laboratories using a method identical with that of the National Bureau of Standards.

The parabolic mirror was measured for spectral reflectance on a spectrophotometer, and the spectral radiance of the lamp was then multiplied by the reflectance to arrive at the apparent filament spectral radiance as computed from the following formula:

$$N_{fil}(\lambda) = N_{cal}(\lambda) \times R(\lambda)$$

Where: $N_{fil}(\lambda)$ is the apparent spectral radiance of filament

$N_{cal}(\lambda)$ is the optronic calibration for the ribbon filament at 35.0 amps, and

$R(\lambda)$ is the reflectance of the parabolic mirror.

Table 3-3 lists the apparent filament spectral radiance for lamp SR-71, which was typically used in field calibrations.

TABLE 3-3

APPARENT FILAMENT SPECTRAL RADIANCE OF LAMPS SR-71

Wavelength (nm)	Spectral Radiance (W/M^2/ster/5 nm)
350	2.92
400	11.62
450	32.85
500	77.19
550	142.87
600	217.12
650	300.80
700	383.16
750	434.32

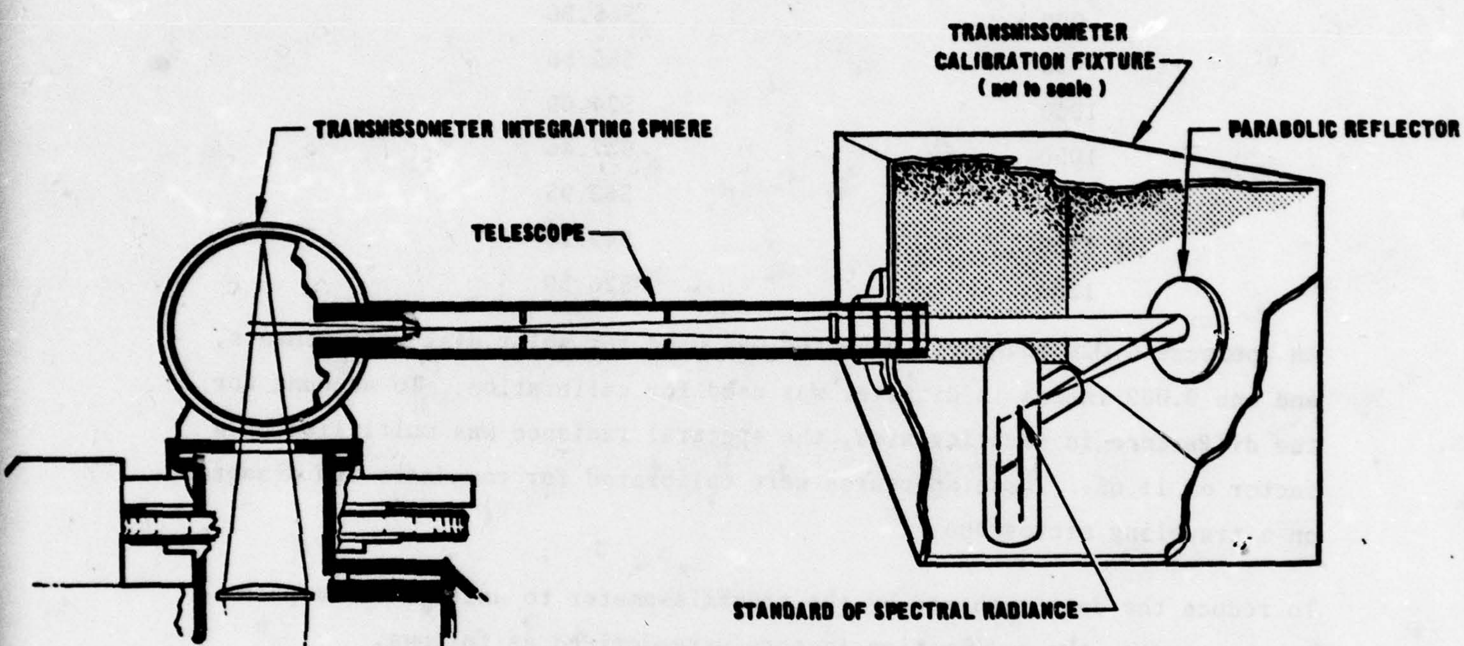

Figure 3-4. Transmissometer Calibration Setup

TABLE 3-3 (CONT'D)

Wavelength (nm)	Spectral Radiance (W/M^2/ster/5 nm)
800	488.40
850	535.04
900	565.50
950	585.66
1000	574.00
1050	537.46
1100	562.95
1150	549.18
1200	526.50

An aperture 0.029 inches in diameter was used for solar disk measurements, and one 0.099 inches in diameter was used for calibration. To account for the difference in sampling area, the spectral radiance was multiplied by a factor of 11.65. These apertures were calibrated for roundness and diameter on a traveling microscope.

To reduce the data gathered by the transmissometer to units of beam path transmittance, the calibration factors were derived as follows.

When the solar disk is measured, the power exiting the objective lens (see Figure 3-5) is:

$$P_o(\lambda) = \frac{\pi}{4} d_o^{\,2} \cdot H_{DK}(\lambda) \cdot t_L(\lambda)$$

Where: d_o is the diameter of the objective lens (clear aperture),

$H_{DK}(\lambda)$ is the mean irradiance of the solar disk (in watts/m^2), and

$t_L(\lambda)$ is the transmittance of the optics.

The diameter of the solar disk image is

$$d_o = \alpha \cdot f_o$$

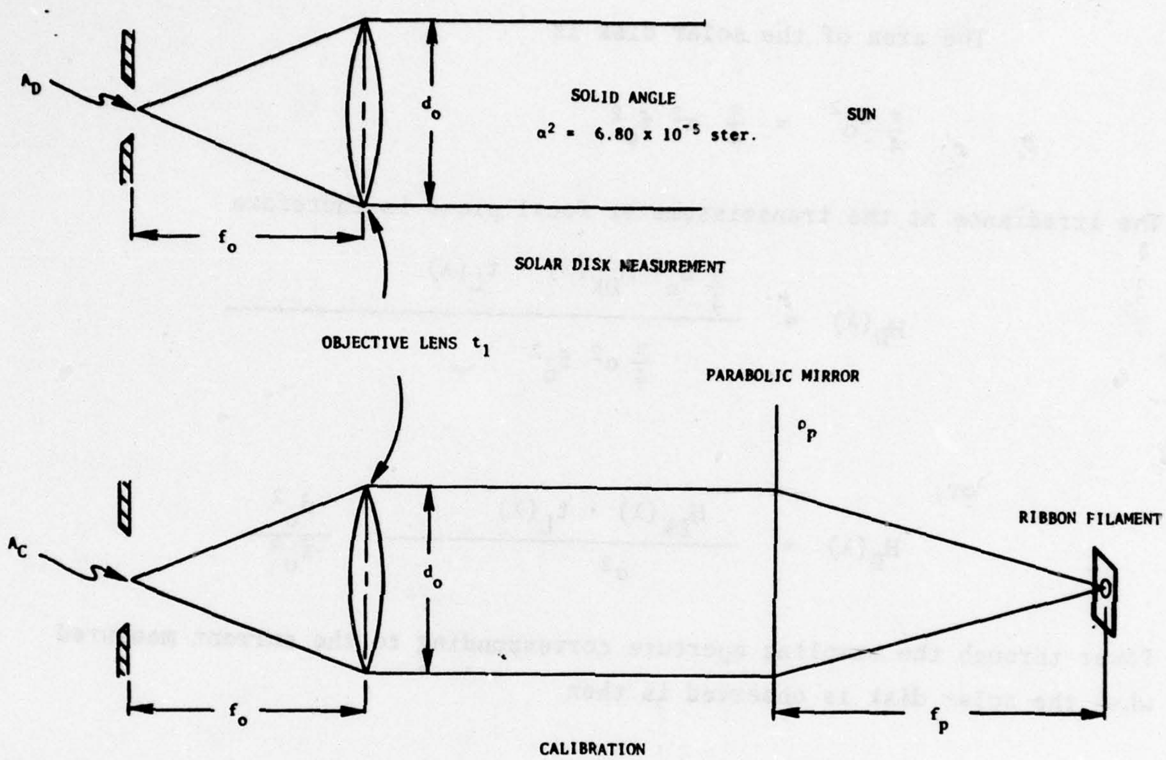

Figure 3-5. Transmissometer Geometry

Where: α is the angle subtended by the sun, and

f_o is the focal length of the objective lens.

The area of the solar disk is

$$\frac{\pi}{4} d_o^2 = \frac{\pi}{4} \alpha^2 f_o^2$$

The irradiance at the transmissometer focal plane is therefore

$$H_D(\lambda) = \frac{\frac{\pi}{4} d_o^2 H_{DK}(\lambda) \cdot t_L(\lambda)}{\frac{\pi}{4} \alpha^2 f_o^2}$$

or,

$$H_D(\lambda) = \frac{H_{DK}(\lambda) \cdot t_L(\lambda)}{\alpha^2} \cdot \frac{d_o^2}{f_o^2}$$

Power through the sampling aperture corresponding to the current measured when the solar disk is observed is then

$$P_D(\lambda) = H_{DK}(\lambda) \cdot A_D = \frac{H_{DK}(\lambda) \cdot T_L(\lambda)}{\alpha^2} \cdot \frac{d_o^2}{f_o^2} \cdot A_D$$

Where: A_D is the area of the sampling aperture when the solar disk is viewed.

The power intercepted and passed through the sampling aperture (A_c) of the transmissometer when it is calibrated with the NBS ribbon filament lamp (see Figure 3-5) is:

$$P_c(\lambda) = N(\lambda) \cdot \Omega_f \cdot A_f \cdot \rho_p(\lambda) \cdot T_L(\lambda)$$

Where: $N_{fil}(\lambda)$ is the apparent radiance of the filament (in watts/m^2/ster),

Ω_f is the solid angle defined by the objective lens and the focal length of the parabolic mirror,

A_f is the area of the filament radiating into Ω_f steradians, and

$\rho_p(\lambda)$ is the spectral reflectance of the parabolic mirror.

But,

$$\Omega_f = \frac{\pi}{4} \cdot \frac{d_o^2}{f_p^2}$$

where, f_p is the focal length of the parabolic mirror

and

$$A_f = A_c \cdot \frac{f_p^2}{f_o^2}$$

After substituting the expression for Ω_f and A_f into the equations for $P_c(\lambda)$, the ratio of $P_D(\lambda)$ to $P_c(\lambda)$ is the ratio of observed currents $(I_D(\lambda)/I_c(\lambda))$ indicated by the radiometer:

$$\frac{P_D(\lambda)}{P_c(\lambda)} = \frac{I_D(\lambda)}{I_c(\lambda)} = \frac{\dfrac{H_{DK}(\lambda) \cdot t_L(\lambda)}{\alpha^2} \cdot \dfrac{d_o^2}{f_o^2} \cdot A_D}{\dfrac{\pi}{4} N_{fil}(\lambda) \cdot \dfrac{d_o^2}{f_o^2} \cdot \rho_p(\lambda) \cdot t_L(\lambda) \cdot A_c}$$

Solving for $H_{DK}(\lambda)$,

$$H_{DK}(\lambda) = \frac{\pi}{4} N_{fil}(\lambda) \cdot \rho_p(\lambda) \cdot \alpha^2 \cdot \frac{A_c}{A_D} \cdot \frac{I_D}{I_c}$$

Because transmittance is defined as the ratio of irradiance inside the atmosphere to that outside the atmosphere, this necessitates correction of H_{Disk} to the equivalent mean disk irradiance via the limb-darkening factor* (LDF), as follows:

$$T(\lambda) = \frac{H_{DK}(\lambda) \cdot LDF(\lambda)}{H_{sc}(\lambda)}$$

* The limb-darkening factor used in these equations is derived in Appendix B to Vol I of this report.

Where $H_{sc}(\lambda)$ is the mean solar constant outside the atmosphere (in watts/m^2/5 nm).

Substituting the expression for $H_{DK}(\lambda)$ into that for the transmittance $T(\lambda)$ yields:

$$T(\lambda) = \frac{\pi}{4} \cdot \frac{N(\lambda)}{H_{sc}(\lambda)} \cdot \rho_p(\lambda) \cdot \alpha^2 \cdot LDF(\lambda) \cdot \frac{A_c}{A_D} \cdot \frac{I_D}{I_c}$$

The factor that is stored for calibrating data from the transmissometer is therefore:

$$\frac{\pi}{4} \cdot \frac{N(\lambda)}{H_{sc}(\lambda)} \cdot \rho_p(\lambda) \cdot \alpha^2 \cdot LDF(\lambda) \cdot \frac{A_c}{A_D} = \text{Cal. Factor}$$

3.2 SPECTRAL CHARACTERISTICS OF RADIOMETERS

3.2.1 Spectral Sensitivity

All four spectroradiometers were calibrated daily providing a substantial data base on the spectral performance of each instrument. S-1 Photomultiplier tubes were used in all radiometers to accommodate the UV to near-IR range requirements in a single instrument. Figures 3-6 through 3-9 show the spectral sensitivities of the four radiometers, including the input optics, filter, monochromators, and detector units. Because the PMT's were changed periodically, these curves can only be considered typical of the spectral responses encountered in the field (see paragraph 3.4.4 of this volume). The spectral sensitivities are in the units used for measurement. In each figure, the depression in sensitivity near 800 nm is caused by the falloff in grating efficiency as the wavelength moves away from the blaze-wavelength near the point of changeover from the *low* to *high* spectrum gratings (780 nm).

An alternative way of describing radiometer spectral performance is to examine typical signal-to-noise functions for each instrument. Figure 3-10 shows these data for instrument calibration and Figure 3-11 shows the data for a typical measurement signal level (30° solar elevation). At the extremes of the wave-

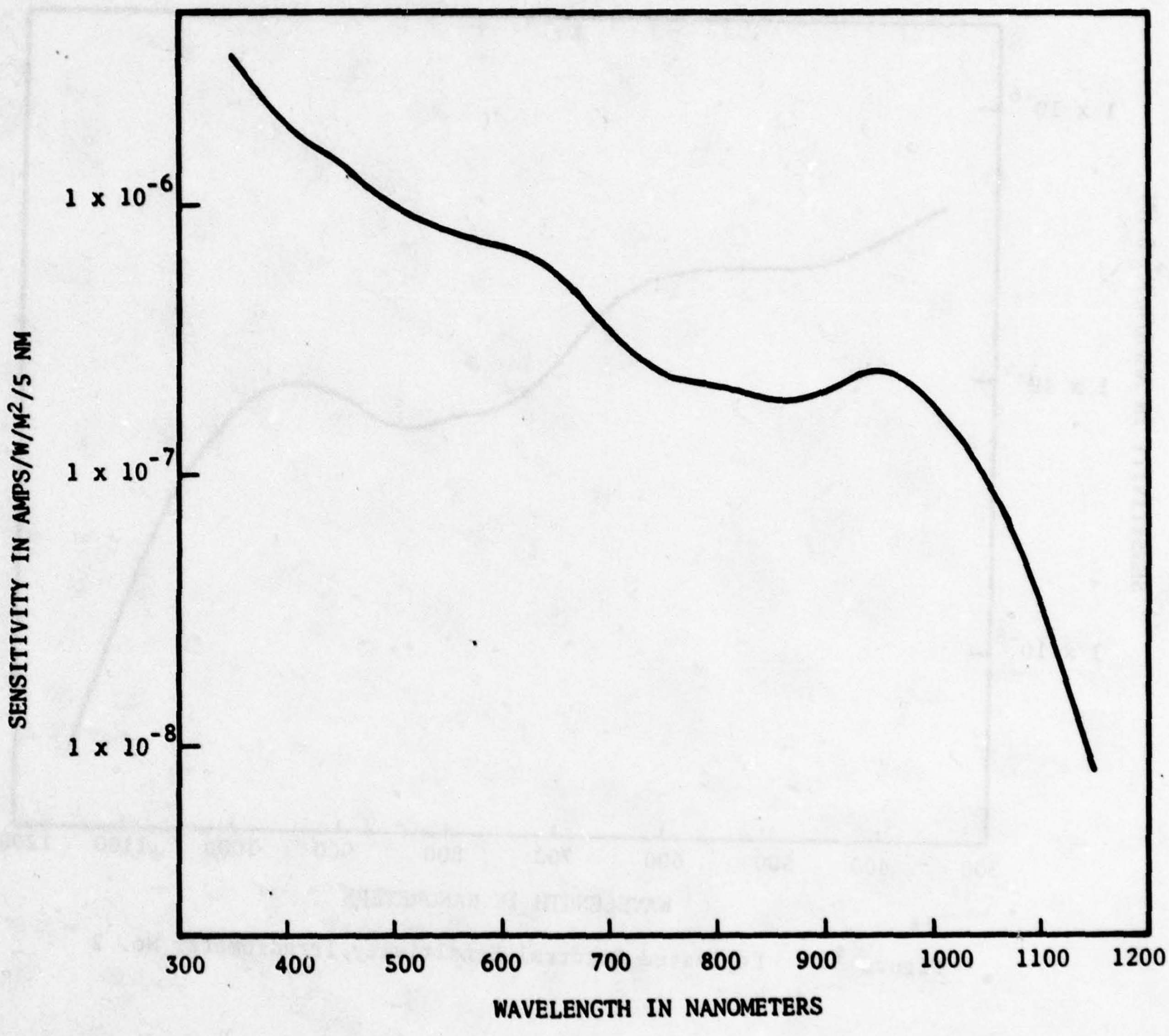

Figure 3-6. Estimated Spectral Sensitivity, Irradiometer No. 1

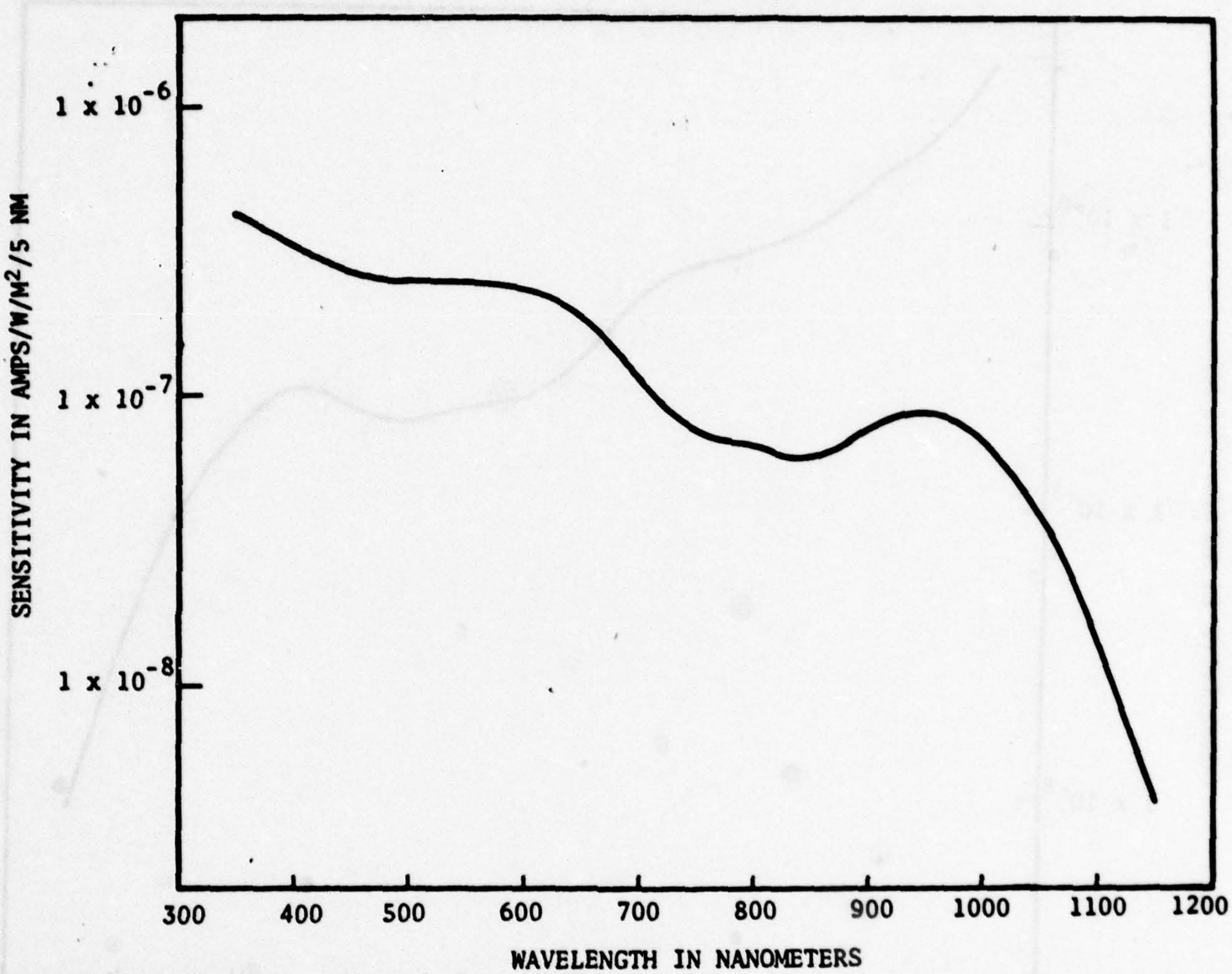

Figure 3-7. Estimated Spectral Sensitivity, Irradiometer No. 2

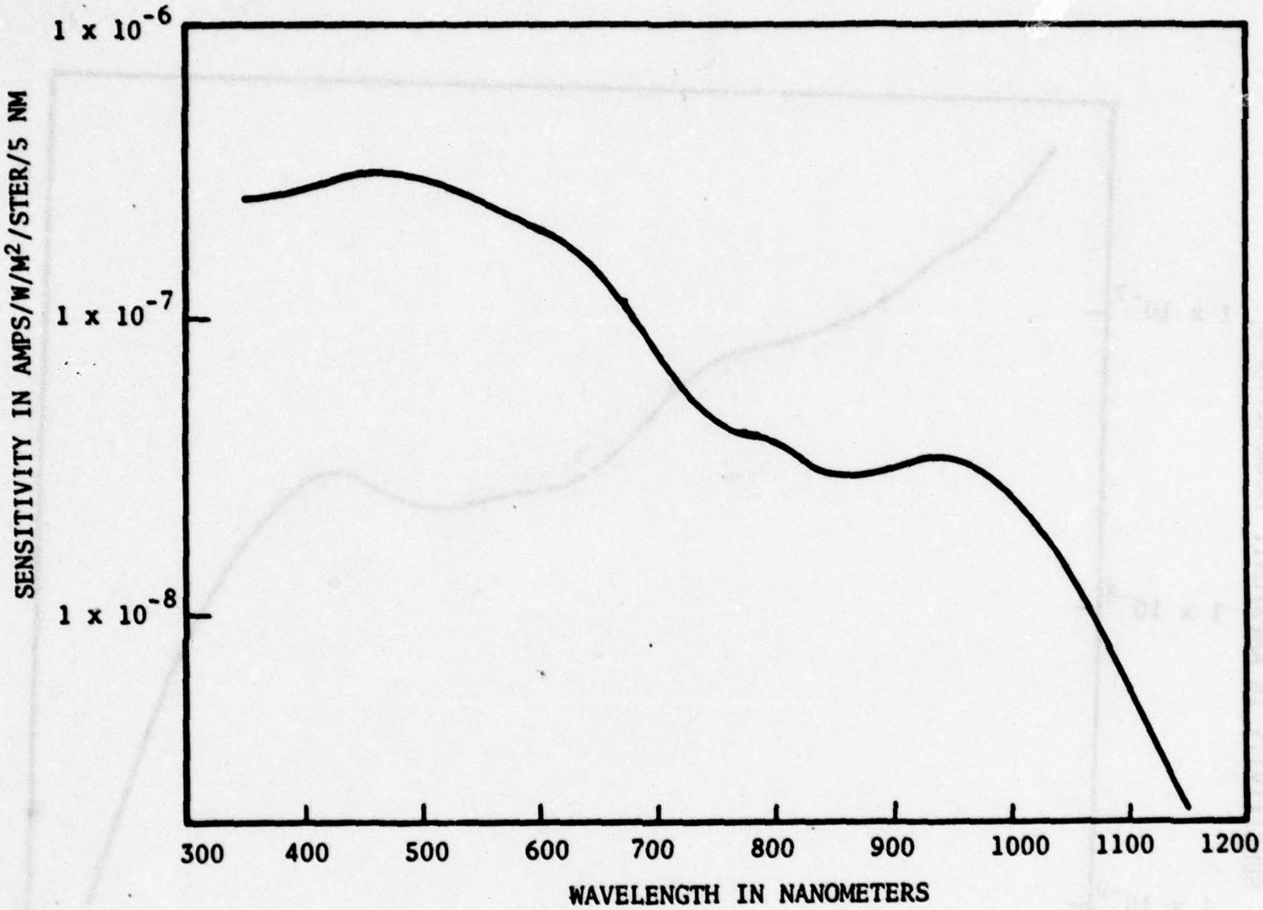

Figure 3-8. Estimated Spectral Sensitivity, Sky Radiometer

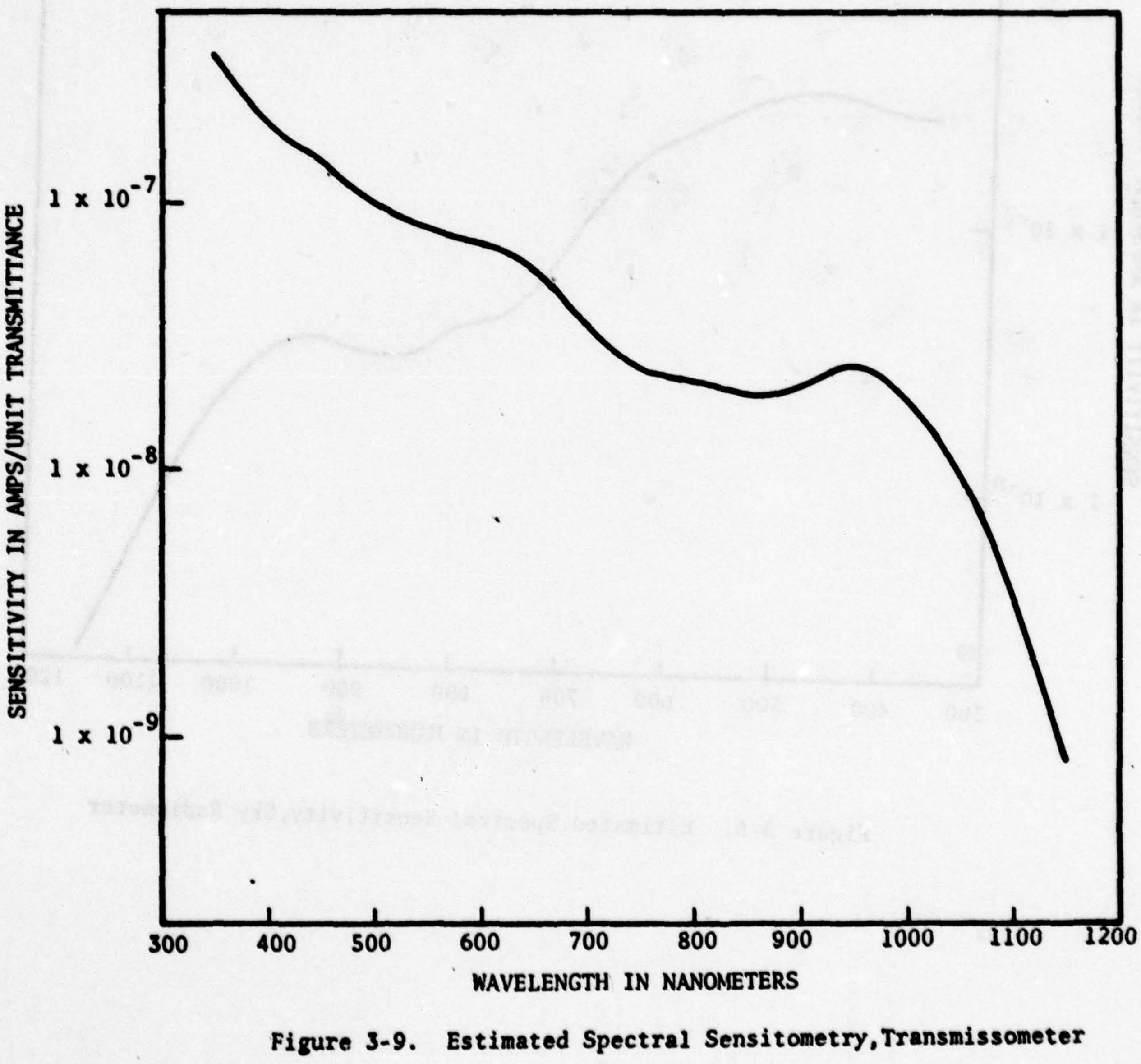

Figure 3-9. Estimated Spectral Sensitometry,Transmissometer

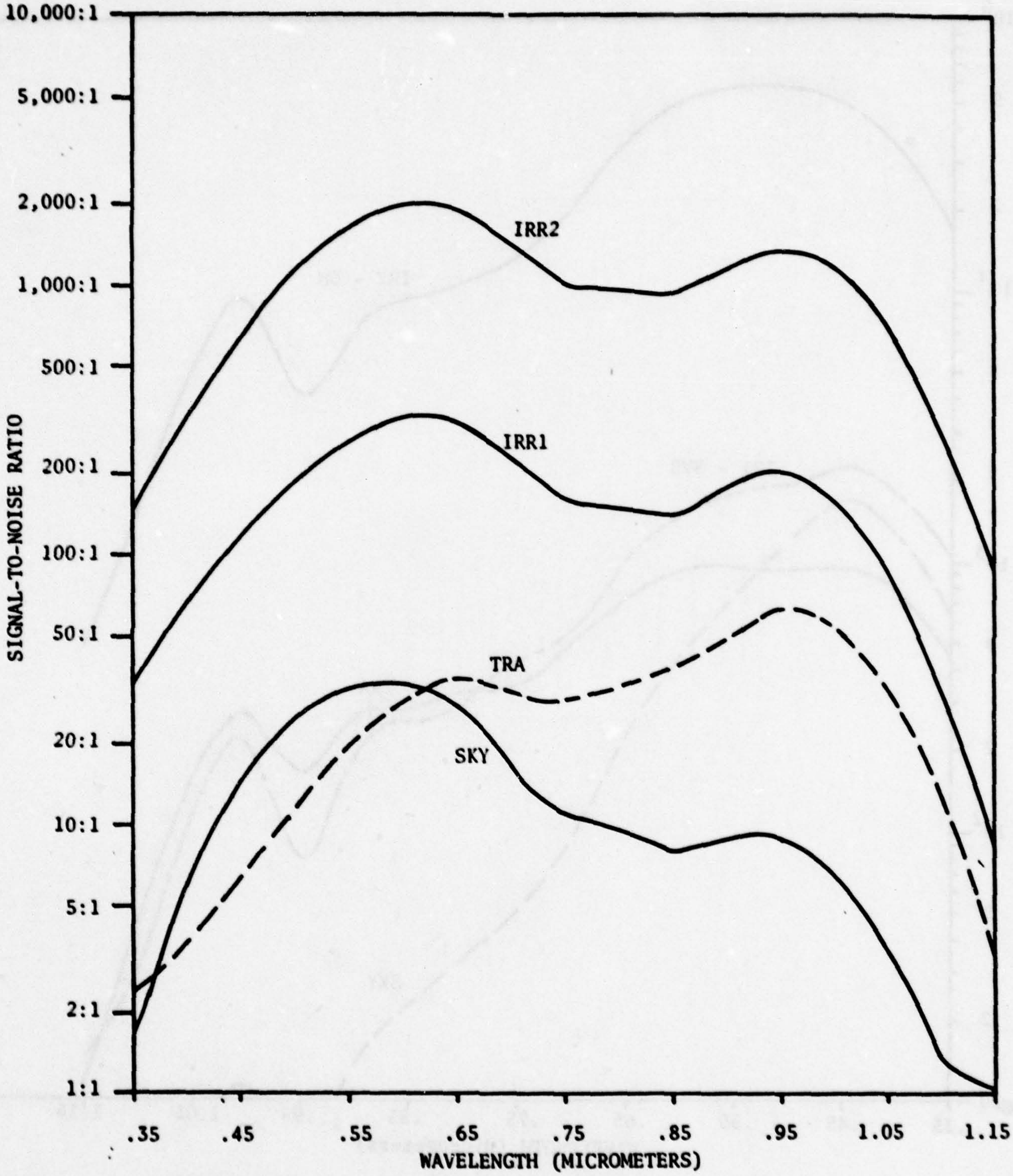

Figure 3-10. Average Calibration Signal-to-Noise Ratios for Spectroradiometers

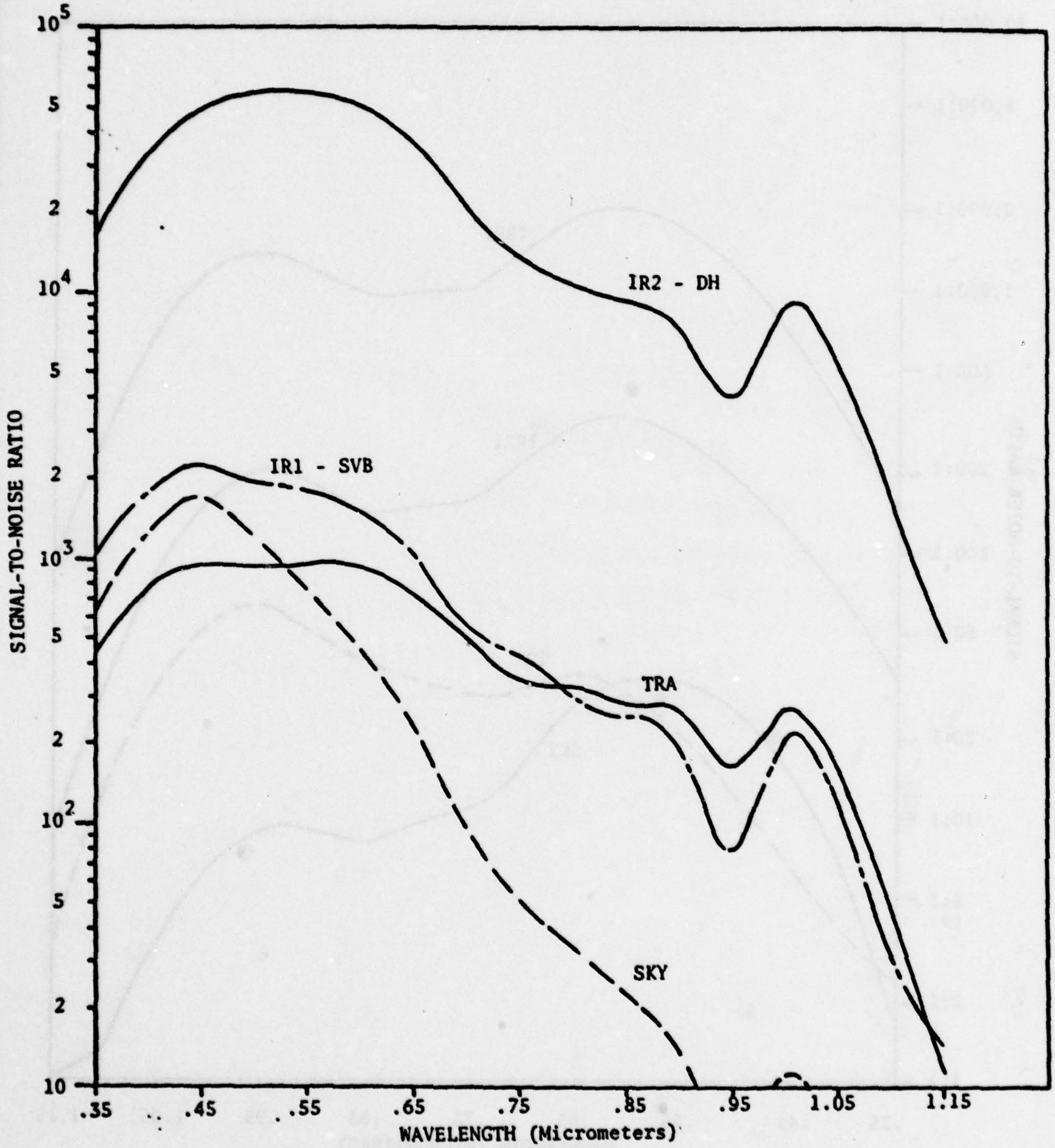

Figure 3-11. Typical Measurement Signal-to-Noise Ratio for Spectroradiometers

length spectrum, the signal-to-noise ratio falls off sharply, causing greater uncertainty in calibration and atmospheric measurement. There is essentially no PMT response after 1.15 micrometers, which is about 50mm short of the original design goal. In general, the two irradiometers had the best signal-to-noise characteristics and the sky radiometer the poorest.

3.2.2 Response Linearity

Spectroradiometer calibrations were handled in a linear manner; that is, it was assumed that the PMT output current was proportional to PMT irradiance. Diurnal changes in measurements as well as the intensity difference between measurements and calibrations caused output currents to range over several orders of magnitude. It was thus necessary to examine instrument linearity over the ranges of intensity experienced in the field by using a constant-intensity source modulated by a calibrated set of neutral density filters (inconel coatings). In each case, the linearity of response could be confirmed over a response range of at least four decades. The experiment was repeated at the four wavelengths 450, 650, 850, and 1050 nm for all four radiometers. A typical response function is shown in Figure 3-12.

3.3 WAVELENGTH ALIGNMENT AND BAND-PASS CALIBRATION

3.3.1 Field Calibration

Each time the trailer was moved and located at a new site, an alignment calibration was performed prior to data acquisition. A mercury (Hg) emission line source was used as a standard to determine points of peak response for aligning the gratings in wavelength. These measurements were also used in estimating the passband of the monochromators.

For the irradiometers the Hg source was placed at the entrance of the integrating sphere; for the sky radiometer the source was placed at the entrance of the telescope; for the transmissometer it was placed in front of the order-sorting filters. An X-Y plotter was connected to the analog wavelength and signal outputs of the 580-13 indicator unit and a trace of the Hg lines was

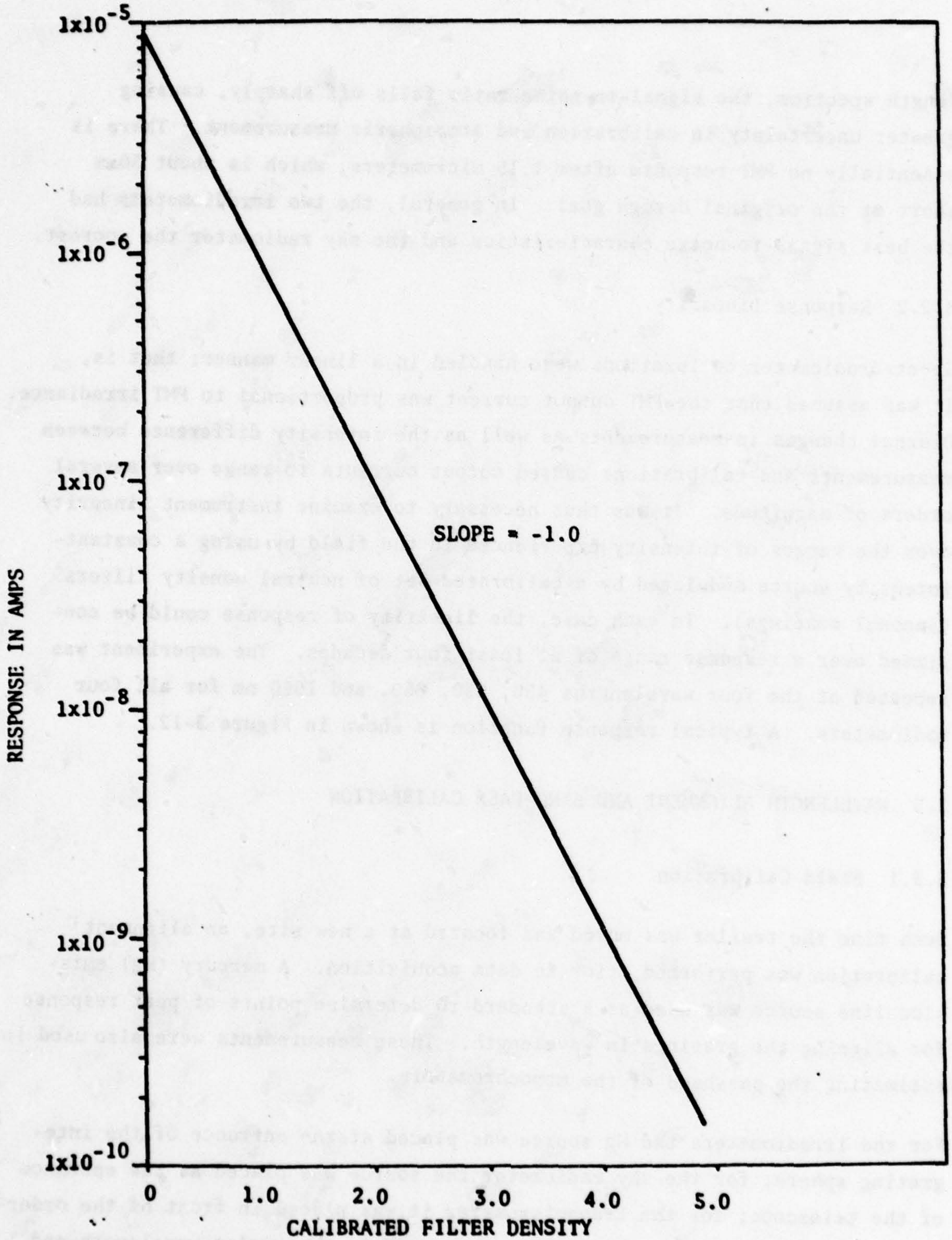

Figure 3-12. Typical Linear Response Characteristic at 650 nm for PMT Serial No. 50010

made. A sample of a typical calibration trace is shown in Figure 3-13. For the wavelength region of 350 to 780 nm, there are four mercury emission lines used for calibration. The lines at 365 nm, 404.7 nm, 435.8 nm and 546.1 nm are first-order emission lines; when doubled by the second order diffraction of the monochromators, they produce four more lines in the infrared.

3.3.2 Half-peak Bandpass

These wavelength calibrations permitted examination of the bandpass of the monochromators and the repeatability of the wavelength calibration. For this examination, it was assumed that the Hg line width was infinitely narrow compared to the band of the monochromators. Table 3-4 lists the peak Hg emission lines, the mean calibrated peak wavelength, and the standard deviation of repeatability of the wavelength calibration to the Hg lines. The data indicate that the repeatability of aligning the gratings was very good, the greatest standard deviation being ±2.10 nm at the peak wavelength of 1158 nm.

The monochromators are designed to provide a nominal 5 nm spectral passband. As can be seen in Figure 3-13, the traces of the peak wavelength were measured for passband width. The mean passband for irradiometer number 1, which is typical of all four spectroradiometers, is 8.85 nm with a standard deviation of ± 1.22 nm. Because some apparent band broadening is to be expected from the plotter response and other signal-realted effects, the true bandpass of the monochromators should be close to the design specification.

3.4 PRECISION AND ACCURACY OF RADIOMETRIC CALIBRATION

3.4.1 Field Calibration of Intensity

Calibration measurements recorded on the van when standard lamps and devices were used are a good indication of the repeatability and uncertainty of the intensity calibration for the instruments. For each day that data was collected,

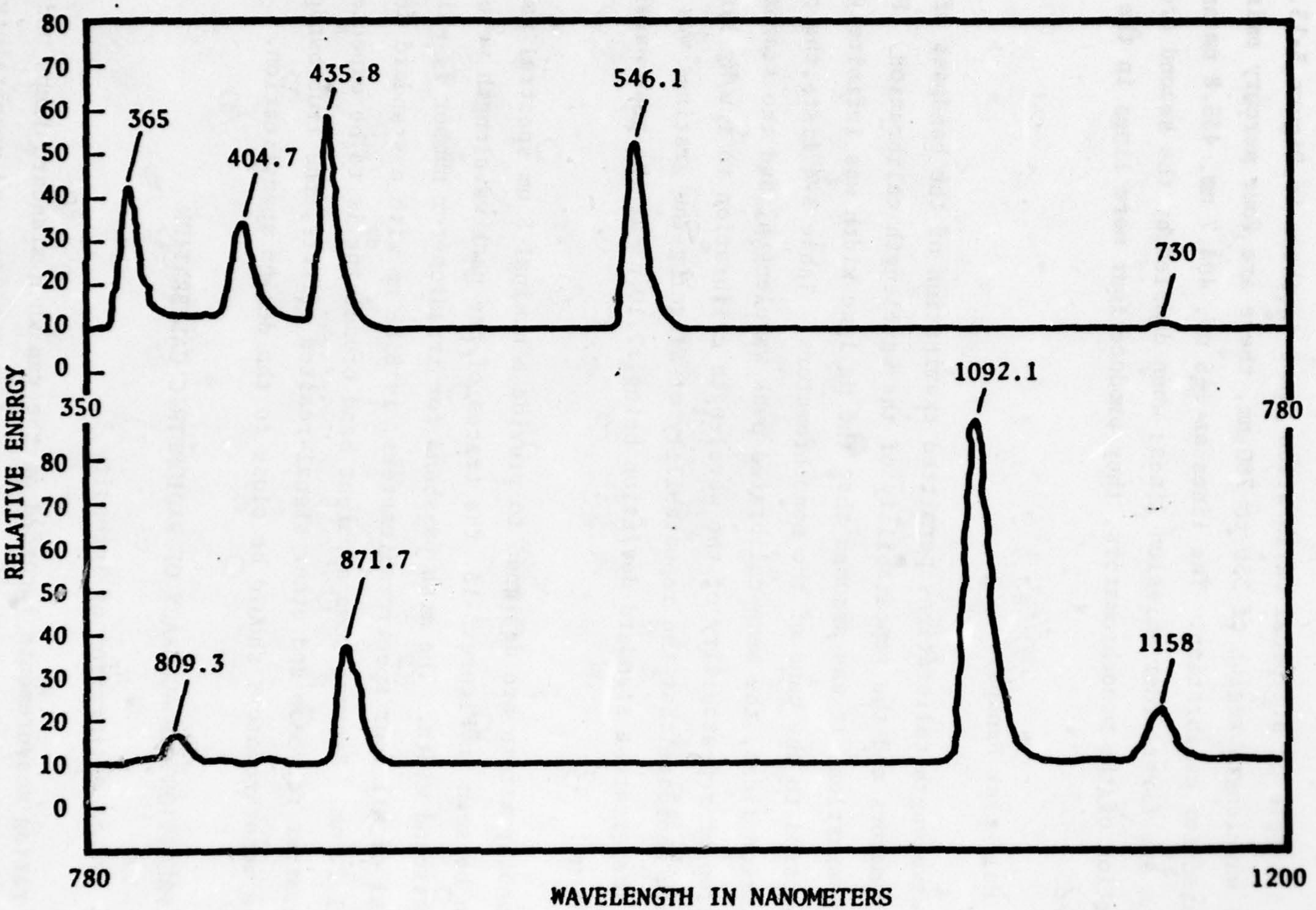

Figure 3-13. Typical Wavelength Calibration for Spectroradiometers

TABLE 3-4

WAVELENGTH CALIBRATION OF THE SPECTRORADIOMETERS

Hg Lines (Nanometers)	Average Calibrated Wavelength (Nanometers)	Standard Deviation of Calibrated Wavelength (Nanometers)
365.0	364.8	± 1.47
404.7	404.8	± 1.52
435.8	435.4	± 1.16
546.1	544.9	± 1.35
730.0*	728.6	± 0.904
809.3*	808.2	± 1.69
871.7*	870.8	± 1.60
1092.1*	1091.1	± 1.45
1158*	1155.9	± 2.10

calibration readings were made by taking measurements in 5 nanometer increments from 350 nm to 1200 nm using lamps of known irradiance to detect and "calibrate out" any day-to-day variation in the instrument. In the on-board RPT** program, the calibration measurements are divided into the spectral lamp power data. This results in a spectral calibration factor for each of the instruments. These factors provided a daily record of the spectral responses of the instruments and a statistical data base with which to study field repeatability and long-term trends.

3.4.2 Field Repeatability

The daily calibrations were pooled to evaluate spectral calibration. Graphs of the field transfer uncertainty as a function of wavelength are shown in Figures 3-14 through 3-17 for the sky radiometer, irradiometers 1 and 2,

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* Values represent the second-order diffraction of the grating, which equals twice the Hg line frequencies.

** See section 4.4 of this report.

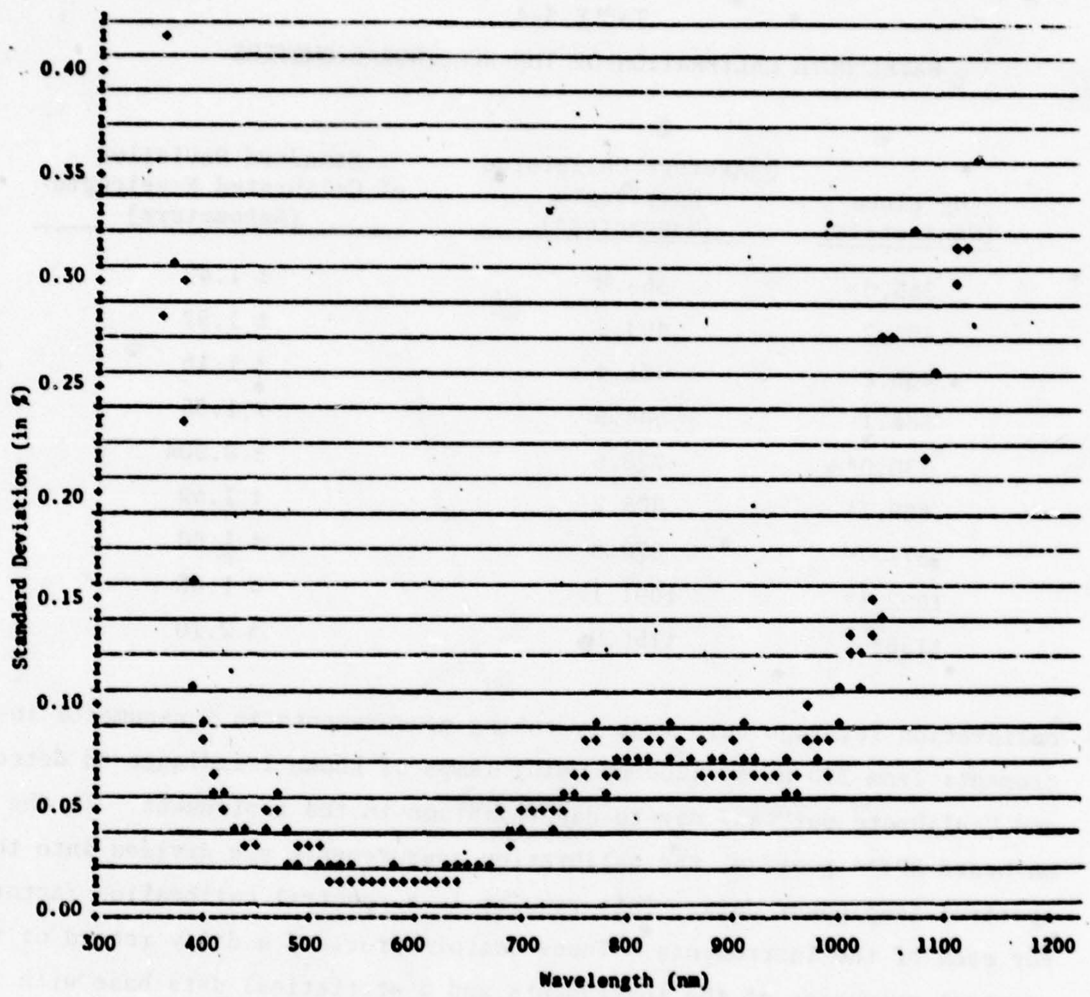

Figure 3-14. Field Transfer Uncertainty for the Sky Radiometer

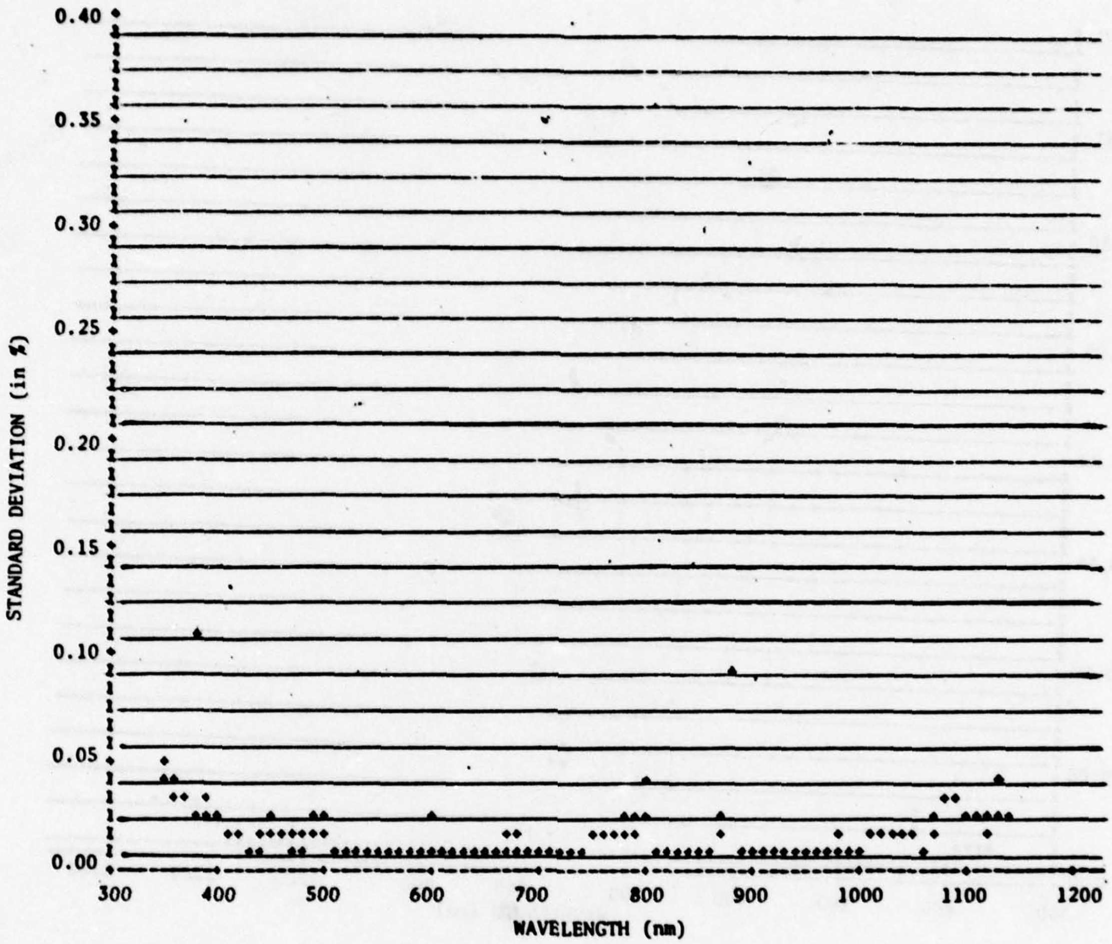

Figure 3-15. Field Transfer Uncertainty for Irradiometer No. 1

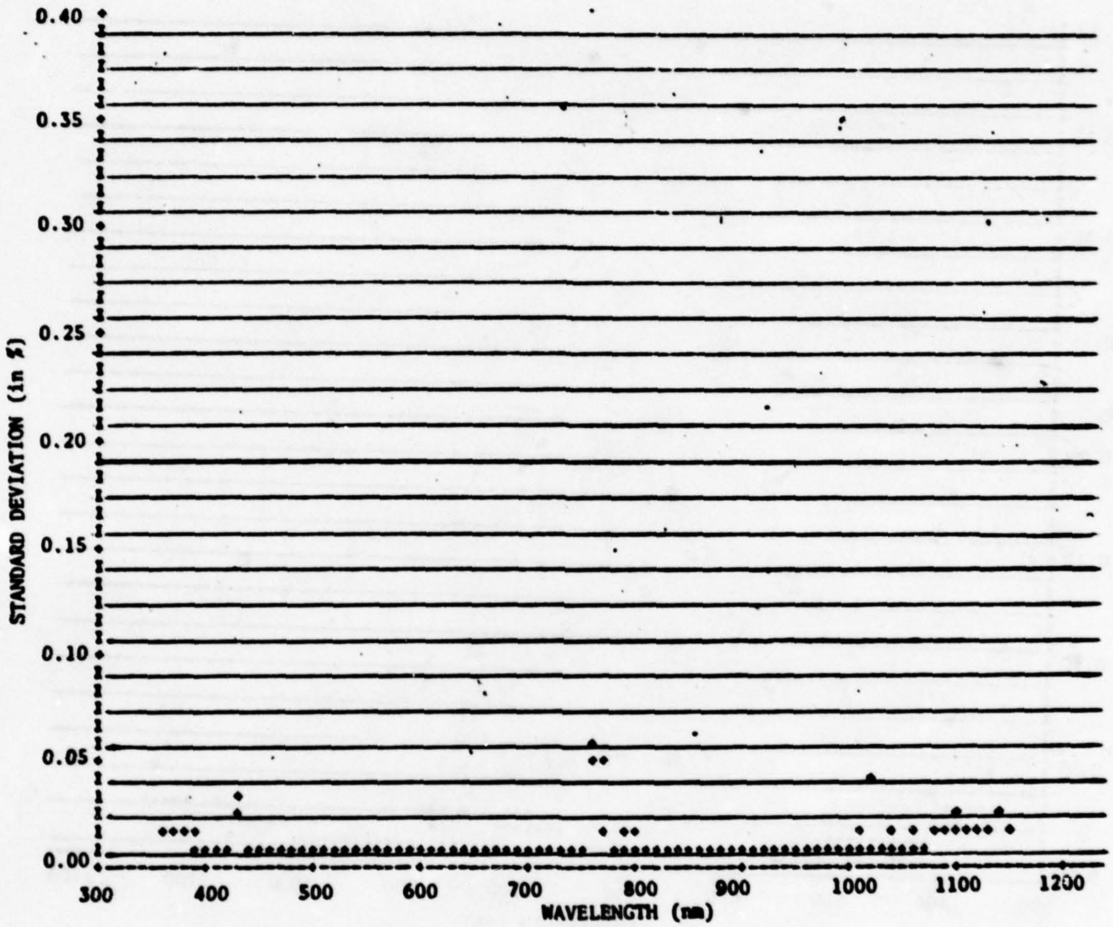

Figure 3-16. Field Transfer Uncertainty for Irradiometer No. 2

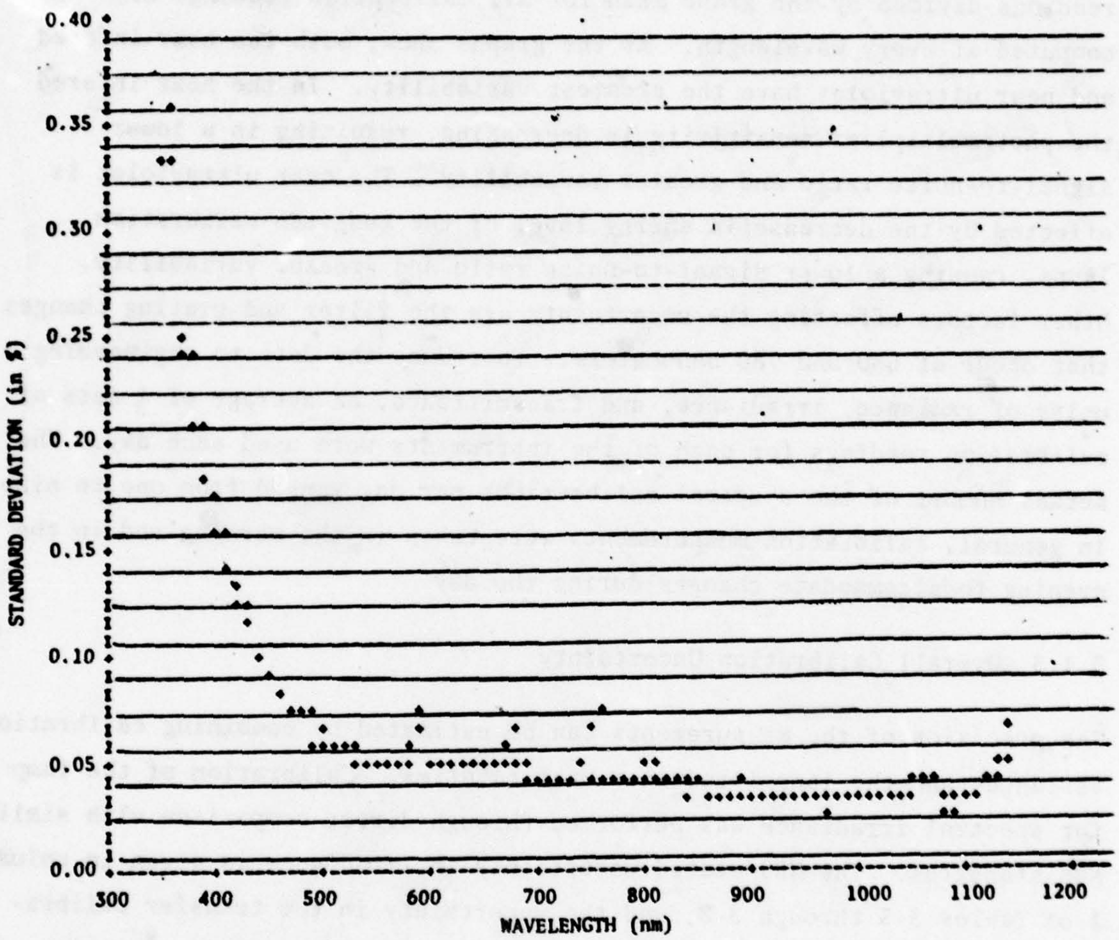

Figure 3-17. Field Transfer Uncertainty for the Transmissometer

and the transmissometer, respectively. The percent field transfer uncertainty is the pooled standard deviation of each day's calibration readings divided by the grand mean for all calibration readings as computed at every wavelength. As the graphs show, both the near infared and near ultraviolet have the greatest variability. In the near infared the photomultiplier sensitivity is decreasing, resulting in a lower signal-to-noise ratio and greater variability. The near ultraviolet is affected by the decrease in energy level of the tungsten calibration lamps, causing a lower signal-to-noise ratio and greater variability. Other factors affecting the uncertainty are the filter and grating changes that occur at 680 and 780 nanometers. To reduce the data to engineering units of radiance, irradiance, and transmittance, an average of 4 sets of calibration readings for each of the instruments were used each day. The actual number of the spectral calibrations per day ranged from one to nine. In general, calibration measurements were taken in the morning and in the evening to accommodate changes during the day.

3.4.3 Overall Calibration Uncertainty

The precision of the measurements can be estimated by combining calibration variances and the lamp irradiance uncertainties. Calibration of the lamp for spectral irradiance was performed through direct comparison with similar NBS standards. The NBS-stated uncertainty in irradiance is given in column 1 of Tables 3-5 through 3-8, and the uncertainty in the transfer calibrations from the NBS standards done by Optronic Laboratories is shown in column 2 of these four tables. The field transfer uncertainty associated with the instruments for a single calibration is listed in column three. The square root of the sums-of-squares of all three uncertainties is an estimate of the overall uncertainty of a single calibration used to reduce data. These are presented in the fourth column of Tables 3-5 through 3-8. These data for all four spectroradiometers are plotted in Figure 3-18.

As can be seen in Figure 3-18, both irradiometers have a percent overall uncertainty of less than 3 percent across the entire spectrum. Because the

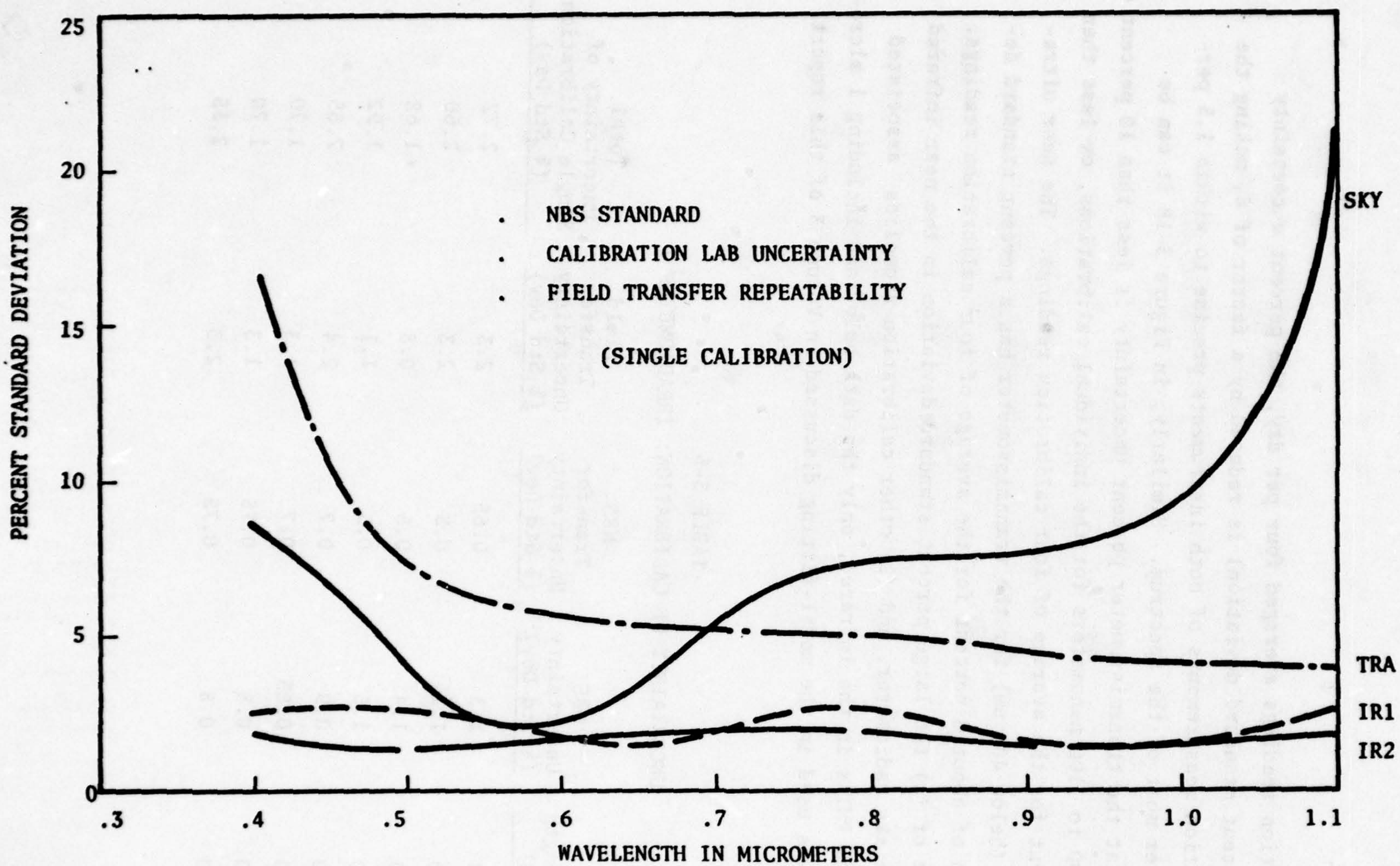

Figure 3-18. Calibration Uncertainty for Radiometers

calibration readings averaged four per day, the percent uncertainty (or percent standard deviation) is reduced by a factor of 4, making the calibration measurements of both instruments precise to within 1.5 percent over most of the spectrum. Similarly, in Figure 3-18 it can be seen that the transmissometer percent uncertainty is less than 10 percent from 500 to 1100 nanometers for the individual calibrations, or less than 5 percent for the average of four calibration readings. The near ultraviolet (below 400 nm) for the transmissometer has a percent standard deviation of about 8 percent for the average of four calibration readings. Because of (1) the large percent standard deviation in the near infrared for the sky radiometer, and (2) other calibration anomolies associated with the PMT's in the infrared, only the data below and including 1 micrometer was used in the model-fitting discussed in Volume 3 of this report.

TABLE 3-5

UNCERTAINTY OF CALIBRATION: IRRADIOMETER 1

Wavelength (nm)	NBS Uncertainty (% Std Dev)	NBS Transfer Uncertainty (% Std Dev)	Field Transfer Uncertainty (% Std Dev)	Total Uncertainty of Single Calibration (% Std Dev)
400	1.3	0.65	2.3	2.72
500	1.1	0.5	2.3	2.60
600	1.4	0.5	0.8	1.68
700	1.5	0.5	1.1	1.92
800	0.9	0.7	2.4	2.65
900	0.85	0.7	1.3	1.70
1000	0.8	0.75	1.3	1.70
1100	0.8	0.75	2.3	2.55

TABLE 3-6

UNCERTAINTY OF CALIBRATION: IRRADIOMETER 2

Wavelength (nm)	NBS Uncertainty (% Std Dev)	NBS Transfer Uncertainty (% Std Dev)	Field Transfer Uncertainty (% Std Dev)	Total Uncertainty of Single Calibration (% Std Dev)
400	1.3	0.65	1.3	1.96
500	1.1	0.5	0.7	1.40
600	1.4	0.5	0.8	1.68
700	1.5	0.5	1.0	1.87
800	0.9	0.7	1.4	1.80
900	0.85	0.7	1.0	1.49
1000	0.8	0.75	1.4	1.78
1100	0.8	0.75	1.6	1.94

TABLE 3-7

UNCERTAINTY OF CALIBRATION: TRANSMISSOMETER

Wavelength (nm)	NBS Uncertainty (% Std Dev)	NBS Transfer Uncertainty (% Std Dev)	Field Transfer Uncertainty (% Std Dev)	Total Uncertainty of Single Calibration (% Std Dev)
400	3.1	1.0	16.2	16.52
500	2.7	1.0	6.7	7.29
600	2.4	1.0	5.3	5.91
700	2.0	1.0	4.7	5.20
800	2.0	1.0	4.6	5.11
900	2.0	1.0	3.9	4.50
1000	2.0	1.0	3.5	4.16
1100	2.0	1.0	3.4	4.07

TABLE 3-8

UNCERTAINTY OF CALIBRATION: SKY RADIOMETER

Wavelength (nm)	NBS Uncertainty (% Std Dev)	NBS Transfer Uncertainty (% Std Dev)	Field Transfer Uncertainty (% Std Dev)	Total Uncertainty of Single Calibration (% Std Dev)
400	1.3	0.65	8.6	8.73
500	1.1	0.5	3.9	4.09
600	1.4	0.5	2.0	2.49
700	1.5	0.5	5.4	5.63
800	0.9	0.7	7.5	7.59
900	0.85	0.7	6.8	6.89
1000	0.8	0.75	9.7	9.77
1100	0.8	0.75	90.1	90.10

3.4.4 Calibration Level Changes Between Days

Since multiple daily calibrations were used for data reduction, long-term changes in spectroradiometer response were automatically eliminated in the process of calibration. It is of historical interest, however, to compare these changes with known detector or standard lamp changes and to isolate any anomalous days of collection. Table 3-9 summarizes all the recorded system changes that would have resulted in a level change in calibration.

TABLE 3-9

SYSTEM CHANGES THAT AFFECTED CALIBRATION

Date	Calibration Device or System Change
6 Aug 1977	Spectral Irradiance Standard Lamp M140 was introduced Sphere Radiance Standard Lamp M140 " " Spectral Radiance Standard Lamp SR-72 " "
15 Dec 1975	Spectral Irradiance Standard Lamp M146 " " Sphere Radiance Standard Lamp M146 " " Spectral Radiance Standard Lamp SR-71 " "
20 Apr 1976	In Irradiometer IR1, the Detector was changed to SN641
8 May 1976	In Irradiometer IR1, the PMT was Changed
12 May 1976	In Irradiometer IR1,the Detector was Changed to SN645
13 May 1976	In Irradiometer IR1, the PMT was changed
26 May 1976	In the Sky Radiometer,the High Voltage Supply and Controller were changed
17 June 1976	In Irradiometer IR1,the PMT was changed to TM46011
17 June 1976	In Irradiometer IR2,the PMT was changed to TM47019
14 July 1976	In Irradiometer IR1,the Integrating Sphere was changed
13 Aug 1976	Spectral Irradiance Standard Lamp M147 was introduced Sphere Radiance Standard Lamp M147 " " In Irradiometer IR1,the PMT was changed to UM01025
22 Aug 1976	In Irradiometer IR1,the PMT was changed to TM46011
8 Sept 1976	The Integrating Sphere for the Sphere Radiance Standard was repainted.

Figures 3-19 through 3-22 are plots of the four spectroradiometer calibration values for the arbitrarily selected value of 650 nm. In these figures, abrupt changes can be seen in the calibration levels corresponding to the dates listed in Table 3-9. Except for the sky radiometer during the period of February/March 1976 and irradiometer No 1 during the period of September/October 1976, all changes in calibration were accounted for by equipment changes. The sky radiometer experienced a dirt buildup problem in its input optics that caused its sensitivity to decrease. This was corrected in April 1976 as can be seen in Figure 3-22. No explanation could be found for the level change in irradiometer No. 1, but since it appeared stable before and after the shift, the data in this period was included in the model analyses.

SECTION 4

COMPUTER SYSTEM AND SOFTWARE

4.1 ONBOARD COMPUTER SYSTEM

Although the four spectroradiometers can be operated either in a purely manual mode or from the controller units, the normal mode of operating the system is under computer control. A Data General 32K, Super-Nova computer processes the signals from 24 positional command and data channels. Figure 4-1 shows the computer system and peripherals (center rack), the controller units for each radiometer (lefthand rack), and the interface electronics between the computer and controller units (righthand rack). The paper tape read/punch and Diablo disc-pack (center rack) can also be seen in Figure 4-1. The normal peripheral devices for recording data, two Sykes single-track recorders, are not visible, but they occupy the uppermost position of the entire rack. The table-mounted unit in Figure 4-1 is a Tektronix graphics display terminal. This is the normal input/output device for operator interface with the computer. The Texas Instrument Silent 700 terminal, which keeps a measurement log, is shown in Figure 4-2. This instrument can be used alternatively to the Tektronix for operator/computer interfaces.

4.2 GENERAL DESCRIPTION OF ON-BOARD SOFTWARE

Programs for radiometer control, diagnostics, data processing, or other utility routines are stored on tape cassettes and direct access discs. These programs are called and executed under RTOS control, or alternatively RDOS control, depending on whether the tape or the disc units, respectively, are on-line.

Operation of the instruments and raw data recording is performed under the control of the RVAN program. As shown in Figure 4-3, the operator sets up

Figure 4-1. Instrument Control Electronics; Left Rack: Controllers, Center Rack: Computer and Peripherals, Right Rack: Interface Electronics, Graphics Terminal

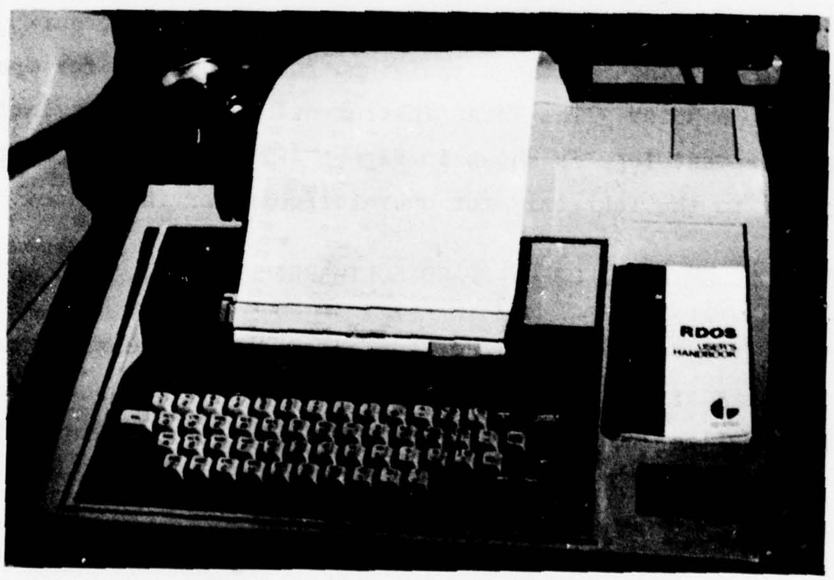

Figure 4-2. Alternate Operator Console or Operation Logging Device

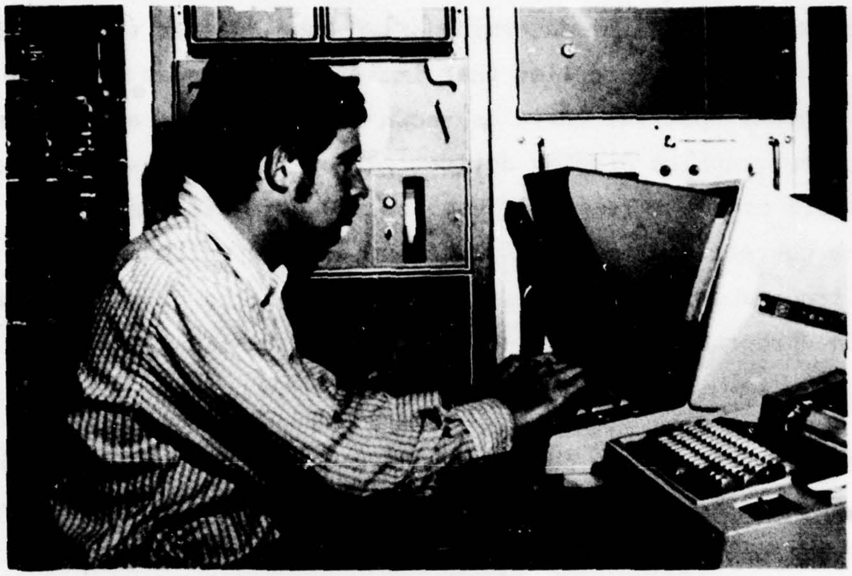

Figure 4-3. Operator Logging-In a Sequence of Instrument Commands Via the Graphics Terminal

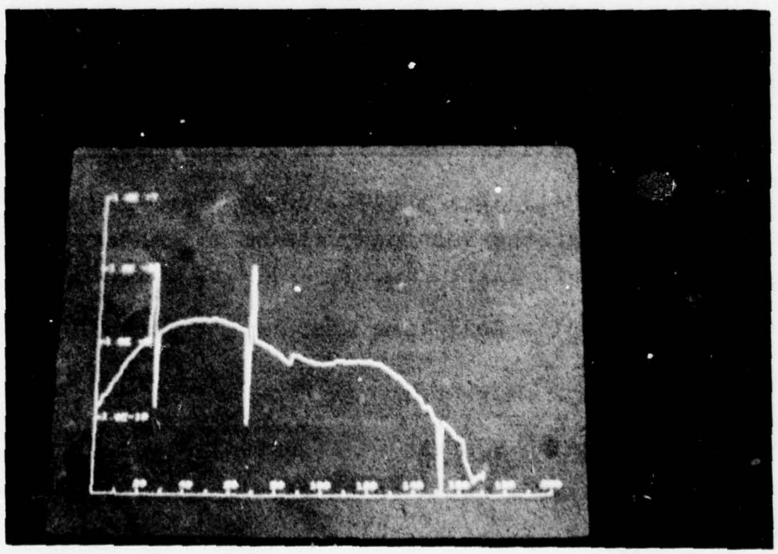

Figure 4-4. Typical Graphics Terminal Display of a Spectral Data Set

a series of data collection commands for all four radiometers; these commands are executed on a predetermined time base. After the data is collected, plotting routines can be called that immediately display and produce hard copy. A typical spectral curve is shown in Figure 4-4, exactly as it would appear on the graphics display device. After the data is collected, programs RPT and RELIB can be called; they combine raw data with instrument calibrations to produce converted data in absolute engineering units and store these data on direct access disc files or sequential files on single-track tape cassettes. The program operation sequence and device links are shown in Figure 4-5.

The calibrated radiometric data, which are written on single-track tape cassettes, can then be sent to another facility for further processing, if necessary. An extensive library of software of this sort has been accumulated that can improve formatting, visualization, and storage of the data on an IBM-370 computer. It is assumed that devices are available for reformatting tape data from single track to nine tracks between the two systems.

4.3 PROGRAM RVAN

4.3.1 General Description of Operations

Two versions of the on-line data acquisition software were used whose operation and output were essentially the same except for the data recording device utilized. The RVAN system recorded data on a Sykes magnetic tape cassette, and the RVANDK system used a contiguous disk file for recording. Both versions were run under Data General's Real Time Operating System (RTOS) and utilized the full 32K memory.

The RVAN and RVANDK operating systems were normally loaded from the moving head disk, but the RVAN system was alternately loaded from cassette tape. Procedures for system loading are explained in detail in Part I of the document MRMS ACQUISITION SOFTWARE: RVAN, and in SYSTEM RELEASE: RVAN, RVANDK (Revision Dated 4/28/77). Parameters defined during system start-up included

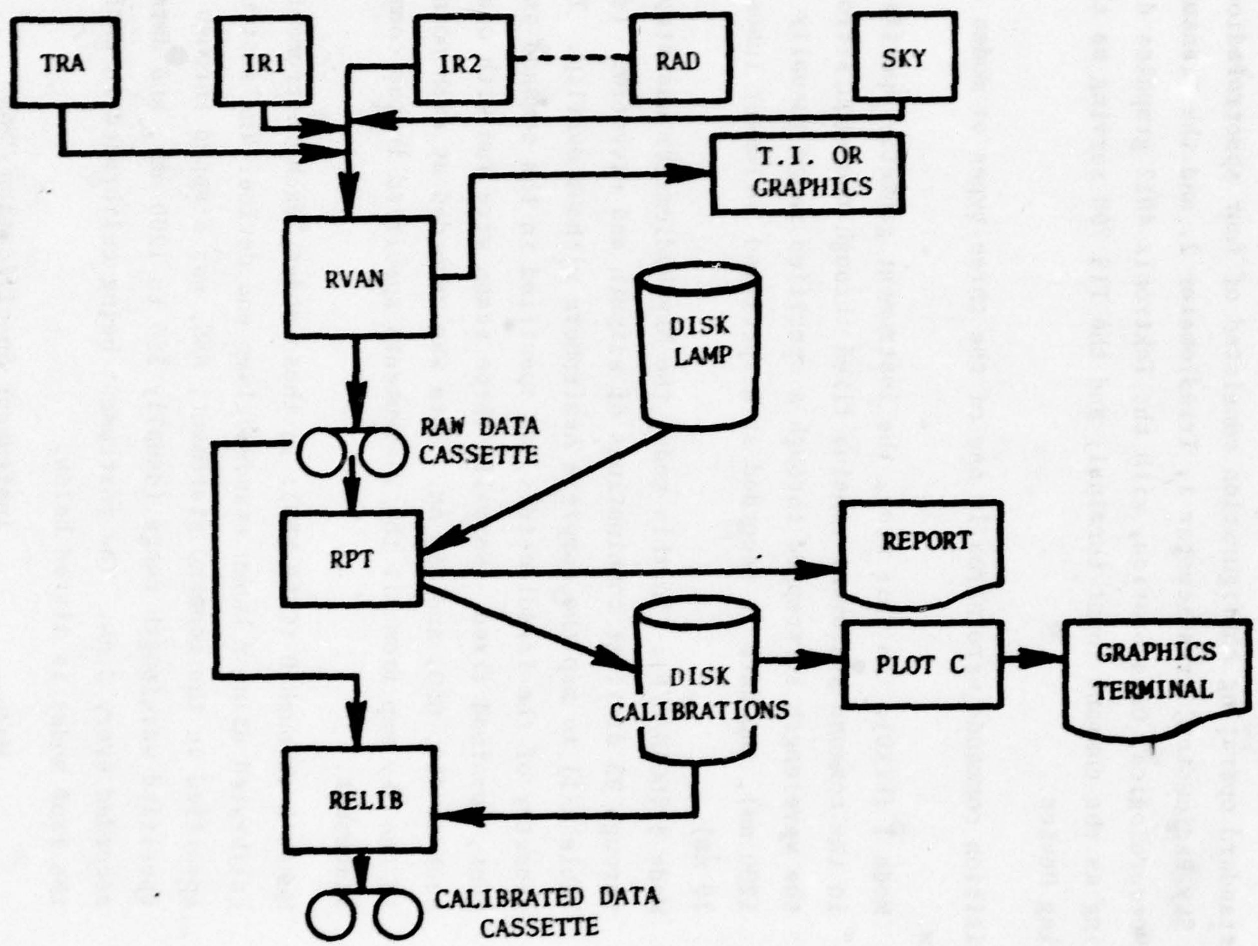

Figure 4-5. Schematic of On-Board Software and Data Flow

GMT date and time; location with respect to latitude, longitude, and elevation; trailer heading; system response to servo errors; data file initialization; and system configuration.

The standard operating configuration consisted of four spectroradiometers (the Sky Radiometer, Irradiometer 1, Irradiometer 2, and the Transmissometer), the Meteorological Data Station, with the Tektronix 4012 graphics display serving as the command input terminal, and the TIS 700 serving as the System Logging Device.

Acquisition commands were normally one of the three types or modes outlined below.

Mode 1 (FIXD): In this mode, the instrument geometry specified in the command statement remains fixed through the acquisition, the wavelength is stepped through a specified range (usually 350-1200 nm), and data is recorded at a specified increment (usually 10 nm).

Mode 4 (SCAN/G/F): In this mode, the Sky Radiometer was stepped through 93 distinct combinations of azimuth and elevation (see Table 4-1) to map the complete hemisphere without overlap. The geometry of the irradiometers, as specified in the command statement, remained fixed. Normally three scans were run with one each at 450, 650, and 850 nm. Data was recorded at each point in the sky map from all the instruments specified in the command statement.

Modes 6 through 9 (CALB NNN): In these modes, each instrument was calibrated using a known standard lamp and device. The instrument specified in the command statement, NNN, was stepped through a specified wavelength range (usually 350 to 1200 nm), and data was recorded every 5 nm. The instrument being calibrated in each of the four modes is listed below.

Mode	Instrument Specification "NNN"
6	SKY
7	IR1
8	IR2
9	TRA

TABLE 4-1

SKY RADIOMETER POINTING ANGLES FOR SKY MAP OPERATION

DATA POINT NO.	AZIMUTH/ ELEVATION AZ, EL	DATA POINT NO.	AZIMUTH/ ELEVATION AZ, EL	DATA POINT NO.	AZIMUTH/ ELEVATION AZ, EL
1--	0, 0	33--	122, 22	65--	240, 82
2--	7, 7	34--	112, 7	66--	276, 67
3--	7, 22	35--	127, 7	67--	279, 52
4--	4, 37	36--	138, 22	68--	269, 37
5--	22, 67	37--	138, 37	69--	252, 22
6--	22, 52	38--	151, 52	70--	247, 7
7--	22, 37	39--	154, 37	71--	262, 7
8--	22, 22	40--	154, 22	72--	269, 22
9--	22, 7	41--	142, 7	73--	277, 7
10--	37, 7	42--	157, 7	74--	285, 22
11--	40, 22	43--	172, 7	75--	288, 37
12--	40, 37	44--	170, 22	76--	302, 22
13--	48, 52	45--	174, 37	77--	292, 7
14--	60, 67	46--	174, 52	78--	307, 7
15--	73, 52	47--	168, 67	79--	318, 22
16--	61, 37	48--	195, 37	80--	307, 37
17--	56, 22	49--	187, 22	81--	307, 52
18--	52, 7	50--	187, 7	82--	312, 67
19--	67, 7	51--	202, 7	83--	330, 52
20--	72, 22	52--	202, 22	84--	326, 37
21--	80, 37	53--	212, 37	85--	334, 22
22--	89, 22	54--	204, 52	86--	322, 7
23--	82, 7	55--	204, 67	87--	337, 7
24--	97, 7	56--	228, 52	88--	351, 7
25--	105, 22	57--	231, 37	89--	351, 22
26--	99, 37	58--	220, 22	90--	345, 37
27--	99, 52	59--	217, 7	91--	356, 52
28--	96, 67	60--	232, 7	92--	348, 67
29--	120, 82	61--	236, 22	93--	360, 82
30--	132, 67	62--	250, 37		
31--	125, 52	63--	253, 52		
32--	118, 37	64--	240, 67		

NO. OF MAP POINTS = 93

4.3.2 Data Recording Format

Whereas program RVAN wrote data on single-track magnetic tape cartridges, program RVANDK wrote data on direct access disk. Either program formats the data as summarized below.

The data file contains as many as 440 256-word blocks. Three block types are used by the RVAN system: the Directory block (D), Header blocks (H), and Raw Data blocks (RD). The first element of each block (ID) identifies its type as indicated below.

ID	Type
0	Directory Block
1	Header Block
2	Raw Data Block

There is always one and only one directory block on a data file. Block 0 is dedicated for this purpose. The directory block has a two-word entry (frame) for each acquisition stored on that file as shown in Figure 4-6. The first entry is the starting block number for that acquisition and the second entry is equal to the number of blocks in that acquisition including its Header (see Figure 4-7). Every unused frame in the Directory block is filled with -1.

FIGURE 4-7

HEADER DIRECTORY FRAME

Word No.	
1	Header Block No.
2	No. of Blocks in Acquisition

A Header block is recorded on the cassette as the first block of each acquisition (see Figure 4-8). It completely specifies the acquisition type and

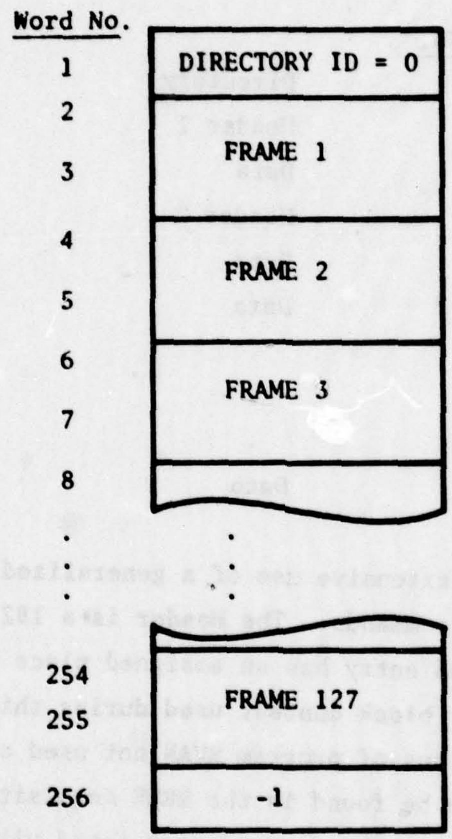

Figure 4-6. Directory Block

indicates the order in which the data for that acquisition is stored in the raw data blocks.

FIGURE 4-8

FILE FORMAT

Block No.	
0	Directory
1	Header 1
2	Data
3	Header 2
4	Data
5	Data
.	.
.	.
.	.
256	Data

The operating system makes extensive use of a generalized action table (a Header) to drive system commands. The Header is a 182-word table with a fixed format. Every command entry has an assigned place in the Header. A complete list of the header block content used during this project is shown in Table 4-2. Certain options of program RVAN not used are indicated by -1 entries. A description can be found in the MRMS Acquisition Software: RVAN. Once the Header mode is known, the command associated with the Header can be executed from the arguments contained therein. Most of the information in a Header (Latitude, Longitude, Elevation, etc.) is filled in at start-up; however, some items are filled in at execution time (date, start and finish times, weather data, etc.). The header block is written on the file as the first block of each data acquisition, as a record of the command. It is used by calibration routines to recover the data in proper sequence.

The format of the Raw Data block is determined completely by the Header for that acquisition. The first word of each RD block is always binary "2" (RD block ID), and the remaining 255 words contain coded radiometric data, as shown in Figure 4-9.

FIGURE 4-9

DATA WORD BIT FORMAT

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

RANGE (assumed to be negative)

DATA (2-digits to the right of the decimal point is implied)

SIGN OF DATA (1 = Positive, 0 = Negative)

TABLE 4-2

CONTENT OF THE HEADER BLOCK

Word No.	Entry		Description
1	Header ID		1 (Identifies this as Header blk)
2	-1		Continuation flag
3	Mode ID		Type acquisition (scan, fixd, calb, etc)
4	No. Blocks with Header		
5	Month		
6	Day		Date
7	Year		
8	Hour	Start	
9	Minute	"	G.M.T. at end of acquisition
10	Second	"	
11	Hour	Finish	
12	Minute	"	G.M.T. at end of acquisition
13	Second	"	
14	Device ID		
15	Device ID		Dev. IDs = SKY -1
16	Device ID		IR1 -2
17	Device ID		IR2 -3
			TRA -4

TABLE 4-2 (Cont'd)

Word No.	Entry	Description
18 to 19	-1	
20	Azimuth	Configuration for first device above
21	Elevation	
22	-1	
23	Azimuth	Same for second device
24	Elevation	
25	-1	
26	Azimuth	Same for third device
27	Elevation	
28	-1	
29	Azimuth	Same as fourth device
30	Elevation	
31 to 37	-1	
38	Wind Speed	Weather data
39	Wind Direction	
40	Humidity	
41	Temperature	
42	Pressure	
43	Lamp ID	Lamp data for instrument
44	Lamp Use Time	Calibration only
45	Min Wavelength	All devices
46	Max Wavelength	
47	Step Wavelength	
48 to 49	-1	
50	No. Pts in Full Map Table	Scan mode only
51 to 61	-1	
62	No. of Wavelengths	Explicit wavelength table, scan mode only
63	First Wavelength	
64	Second "	
65	Third "	

TABLE 4-2 (Cont'd)

Word No.	Entry	Description
66 to 82	-1	
83	Filter #1 Min Wav.	Filter specifications for four positions
84	Filter #1 Max Wav.	
85	Filter #2 Min Wav.	
86	Filter #2 Max Wav.	
87	Filter #3 Min Wav.	
88	Filter #3 Max Wav.	
89	Filter #4 Min Wav.	
90	Filter #4 Max Wav.	
91 to 94	0	
95	Lat. Deg.	Site location
96	Lat. Min.	
97	Lat. Sec	
98	Long. Deg	
99	Long. Min.	
100	Long. Sec	
101	Elevation	Height above mean sea level (feet)
102 to 181	Comments	Up to 160 characters, 2 characters per word
182 to 256	-1	

The data is recorded in the order in which it is taken during the acquisition. Data is recorded for each instrument specified in the Header in the order of the Header's ID list. Figure 4-10 shows the RD block format for the different acquisition modes.

After the commanded acquisition has been made, the event is logged in hard copy as a System Log. This log is a sequential record of all transactions made during a day's operation of the RVAN system. It provides the operators with a hard copy record of each acquisition attempt, acquisition terminations, and limited servo error messages. An example of the System Log is shown in Figure 4-11.

FIGURE 4-10

RD BLOCK FORMATS

Word No.	Mode = 1 or 6-10	Mode = 4
1	2	2
2	RD(λ1,D1)	RD(G1,λ1,D1)
3	RD(λ1,D2)	RD(G1,λ1,D2)
.	.	.
.	.	.
.	.	.
	RD(λ2,D1)	RD(G2,λ1,D1)
	RD(λ2,D2)	RD(G2,λ1,D2)
	.	.
	.	.
	.	.
	RD(λ3,D1)	RD(G3,λ1,D1)
	RD(λ3,D2)	.
	.	.
	.	.
	.	RD(G1,λ2,D1)
		.
		.
		.
		RD(G2,λ2,D1)
		.
		.
		.

The values in the table above; i.e., RD (λ1,D1) etc. correspond to the spectroradiometer PMT Anode currents read on the 585-13 indicator unit. The elements within the parentheses are:

λn is the wavelength setting for all instruments

Dn is the device ID order in the Header

Gn is the Azimuth/Elevation setting of the Sky Radiometer.

Figure 4-11

Command Example of the System Log

```
FILENAME ? RVAN

RTOS REV 03.02
RVAN REV 2.00 (CASS)
DEFAULT INIT (0-NO,1-YES)?0
G.M.D. (M,D,Y) ? 09,27,75
G.M.T. (H,M,S) ? 17,30,00
GEOGRAPIC LOCATION
LAT.(DEG,MIN,SEC)=36,57,00
LONG.(DEG.,MIN.,SEC.)=-116,-03,00
ELEV. (FT. ABV SEA LEV.) =3924
VAN AZ(N DEG.)=0
OP. CON.=?(1-TTY,2-TTY1)2
MOVE TO OPERATOR'S CONSOLE = TTY1


RVAN INIT.  -   9/27/75 - 17:30:39
    LAT.   =    36: 57:  0
    LONG.  = -116: -3:  0
    ELEV.  =    3924

 -MODE-             TIMES   WAV(MIN)  WAV(MAX)  WAV(STP)  INSTR'S

 NEW CASS. LOADED WITH     0 ACQUISITIONS

 -MODE-             TIMES   WAV(MIN)  WAV(MAX)  WAV(STP)  INSTR'S

 CALB SKY         17:31:32     350      1200        5    1 -1 -1 -1

 CALB SKY         17:33: 3

 CALB IR1         17:33:16     350      1200        5    2 -1 -1 -1

 CALB IR1         17:34:54

 CALB IR2         17:35: 0     350      1200        5    3 -1 -1 -1

 CALB IR2         17:36:33

 CALB TRA         17:36:39     350      1200        5    4 -1 -1 -1

 CALB TRA         17:39:11

 FIXD             17:45: 0     350      1200       10    1  2  3  4

 FIXD             17:45:52

 SCAN/F GEO       17:50: 0      -1        -1       -1    1  2  3  4

 SCAN/F GEO       17:52:31
```

4.4 THE RPT PROGRAM

4.4.1 Description of Operation

The RPT program is the first of two programs used to reduce raw spectral data to engineering units. RPT is used to assemble calibration readings and calibration lamp irradiance data in preparation for the actual data reduction later performed in the RELIB program. For a complete description of the RPT program that is beyond the depth of this report, refer to Part II of the document Mobile Radiometric Laboratory On-Board Data Processing Software.

For RPT to operate as shown in the flow chart in Figure 4-12, two input files are needed. The first file, on cassette, contains the current readings recorded by program RVAN. The second file, on disk, contains lamp spectral calibration factors in engineering units for each instrument. These lamp spectral calibration data were discussed in paragraph 3.1 above. Each acquisition of spectral current readings recorded by RVAN has at least two records associated with it. The first is a header record that gives information on the time, place, conditions, and type (or mode) of acquisition, (as described above in paragraph 4.3). Subsequent records contain the data associated with a particular data acquisition.

The RPT program reads each header record from the RVAN file and extracts (1) the date and time of the acquisition, (2) the instruments in operation, and (3) any comments (inputs) by the operator on the validity of the acquisition or its type (see paragraph 3.4.1 above).

If the header record indicates a calibration, RPT searches the lamp spectral irradiance data file for the lamp with which the calibration was performed. The appropriate lamp data is then divided by the calibration readings resulting in a calibration factor that may be used by the RELIB program to reduce into engineering units the raw data collected by RVAN. Each calibration factor is stored on the disk in the file CAL.DAT.

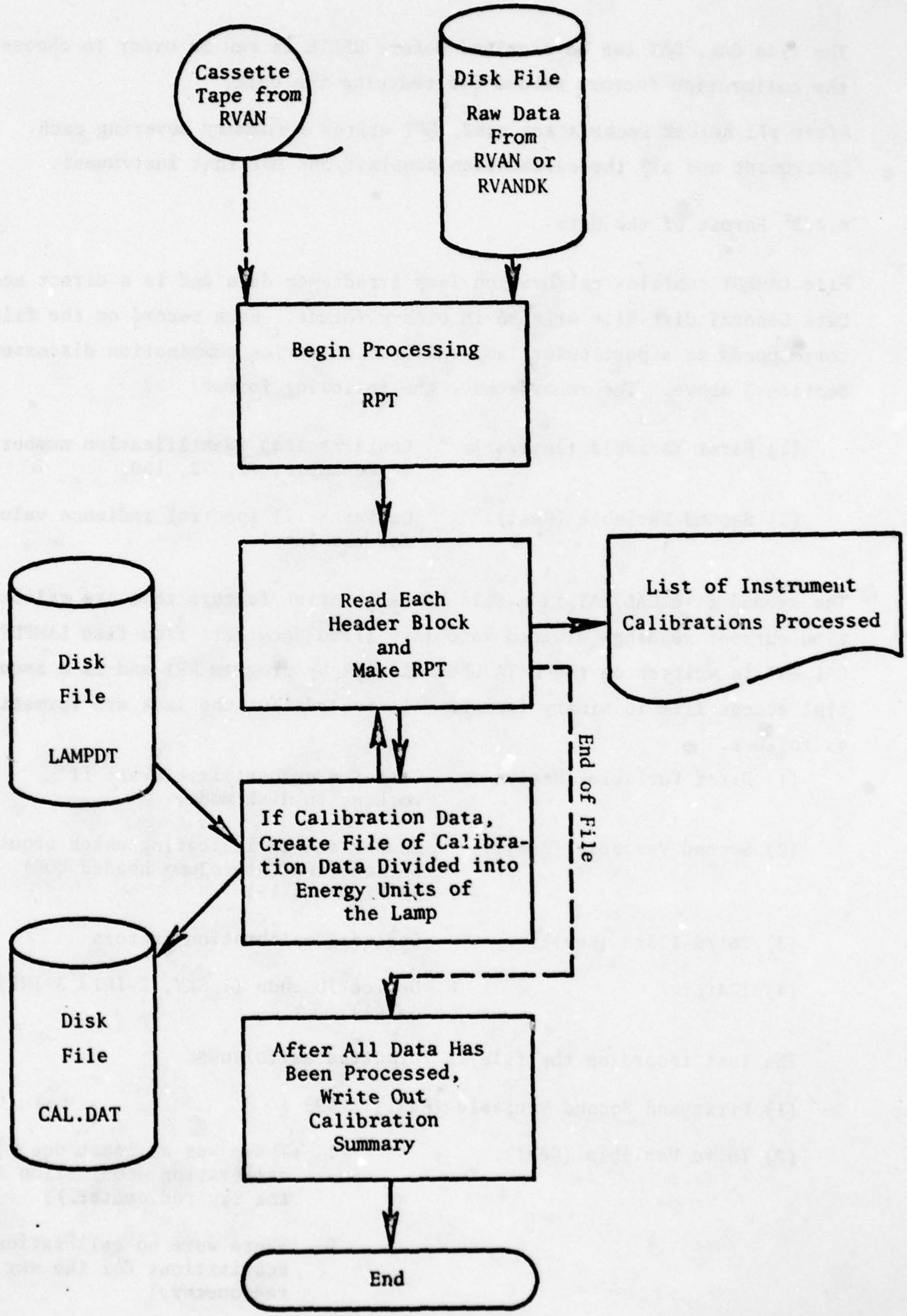

Figure 4-12. Flow Chart of RPT Program

The file CAL. DAT can be examined before RELIB is run in order to choose the calibration factors needed for reducing the data.

After all header records are read, RPT writes a summary covering each instrument and all the calibration acquisitions for that instrument.

4.4.2 Format of the Data

File LAMPDT contains calibration lamp irradiance data and is a direct access Data General disk file written in binary format. Each record on the file corresponds to a particular lamp/calibration device combination discussed in Section 3 above. The records have the following format:

(1) First Variable (Integer):	Contains lamp identification number; for example, 71, 72, 160.
(2) Second Variable (Real):	Contains 171 spectral radiance values for the lamp.

The second file CAL.DAT is a file of calibration factors that are calibration current readings divided into lamp irradiance data from file LAMPDT. CAL.DAT is written on the DATA GENERAL disk by program RPT and is a sequential access file in binary format. All records but the last are formatted as follows:

(1) First Variable (Real):	Cassette number; irrelevant if working in disk mode.
(2) Second Variable (Real):	Header number indicating which acquisition (see the column headed HDR# in Figure 4-13).
(3) Third-173rd (Real):	Spectral calibration factors
(4) 174th:	Device ID code (1-SKY, 2-IR1, 3-IR2, 4-TRA).

The last record on the file is formatted as follows:

(1) First and Second Variable (Real): 999

(2) Third Variable (Real):
- 1 (There was at least one calibration acquisition for the sky radiometer.)
- 0 (There were no calibration acquisitions for the sky radiometer.)

(3) Fourth Variable (Real): 1 (There was at least one calibration acquisition for irradiometer No.1.)

0 (There were no calibration acquisitions for irradiometer No.1.)

(4) Fifth Variable (Real): 1 (There was at least one calibration acquisition for irradiometer No.2.)

0 (There were no calibration acquisitions for irradiometer No.2.)

(5) Sixth Variable (Real): 1 (There was at least one calibration acquisition for the transmissometer.)

0 (There were no calibration acquisitions for the transmissometer.)

(6) Seventh Variable (Real): 1 (There was at least one calibration acquisition for the utility radiometer.)

0 (There were no calibration acquisitions for the utility radiometer.)

(7) Eighth Variable (Real): Total number of acquisitions.

The RPT program also provides the operator with a log of all calibrations found on the tape cassette or disk file being processed, as well as a list of all header blocks encountered. After the appropriate lamp/device spectral data are combined with the calibration current readings, the program produces a summary, by instrument, of header block numbers corresponding to raw calibration data blocks. These outputs are shown in the example in Figure 4-13. For a complete description of Program RPT, refer to Documentation for the Mobile Radiometric Laboratory On-Board Software Data Processing, Part II: Calibration Software.

4.5 PROGRAM RELIB

4.5.1 General Description of Operation

RELIB is the second of two programs needed to convert the raw spectral data recorded in amperes by Program RVAN into engineering units of radiance, irradiance, and transmittance. In Program RELIB, the data on the CAL.DAT file created by program RPT was multiplied by the raw current readings to produce a new file of calibrated data in engineering units.

Figure 4-13

Example of RPT Output

```
RPT
DO YOU WANT OUTPUT ON CRT (1-YES,0-NO)? 0
CASE# NDR#    DATE     TIME     TYPE         LAMPID   DEVICES
  1    1    9/25/75  12:11:31  CALIB TRA       1      4.

  1    2    9/26/75  12:16:38  CALIB TRA       1      4.

  1    3    9/26/75  12:19:59  CALIB TRA       1      4.

  1    4    9/26/75  12:23:20  CALIB TRA       1      4.

  1    5    9/26/75  12:28: 7  CALIB TRA       1      4.

  1    6    9/26/75  12:31:38  CALIB TRA       1      4.

  1    7    9/26/75  12:35:53  CALIB IR1       3      2.

  1    8    9/26/75  12:39:29  CALIB IR1       3      2.

  1    9    9/26/75  12:42:45  CALIB IR1       3      2.

  1   10    9/26/75  12:48:22  CALIB IR2       3      3.

  1   11    9/26/75  12:53:11  CALIB IR2       3      3.

  1   12    9/26/75  12:54:39  CALIB IR2       3      3.

  1   13    9/26/75  13: 6:19  CALIB SKYR      5      1.

  1   14    9/26/75  13:11:59  CALIB SKYR      5      1.

  1   15    9/25/75  13:16:17  CALIB SKYR      5      1.

  1   15    9/26/75  13:23: 7  CALIB SKYR      5      1.

  1   17    9/25/75  13:23:54  CALIB SKYR      5      1.

  1   18    9/26/75  13:27:53  CALIB SKYR      5      1.

   ***NO FINISH TIME NDR#=    19
  1   19    9/25/75  15: 4:20  FIXGEOMETRY    -1      1, 2, 3, 4.

   ***NO FINISH TIME NDR#=    20
  1   20    9/25/75  15:11:46  FIXGEOMETRY    -1      1, 2, 3, 4.

   ***NO FINISH TIME NDR#=    21
  1   21    9/25/75  15:40: 8  FIXGEOMETRY    -1      1, 2, 3, 4.

   ***NO FINISH TIME NDR#=    22
  1   22    9/26/75  16:55: 0  FIXGEOMETRY    -1      1, 2, 3, 4.

   ***NO FINISH TIME NDR#=    23
  1   23    9/29/75  21:28:35  FIXGEOMETRY    -1      1, 2, 3, 4.

  1   24    9/28/75  22:17:50  FIXGEOMETRY    -1      1, 2, 3, 4.

  1   25    9/28/75  22:22:37  SCAN/Q/F       -1      1, 2, 3, 4.

  1   26    9/29/75  22:32:42  FIXGEOMETRY    -1      1, 2, 3, 4.

  1   27    9/29/75  22:39: 1  SCAN/Q/F       -1      1, 2, 3, 4.

  1   28    9/29/75  22:49:40  FIXGEOMETRY    -1      1, 2, 3, 4.

   ***NO FINISH TIME NDR#=    29
  1   29    9/29/75  22:53:46  SCAN/Q/F       -1      1, 2, 3, 4.

  1   30   11/ 6/75  20:14:38  CALIB IR2       3      3.

  1   31   11/ 6/75  20:21:55  CALIB IR2       3      3.

  1   32   11/ 6/75  20:25:57  CALIB IR2       3      3.
IS THERE ANOTHER TAPE? (1-YES,0-NO) 0

CALIBRATION SUMMARY
          INSTR          NDR#
          -----          ----
          SKYR-1         13  14  15  16  17  18
          IR1-2          7   8   9
          IR2-3          10  11  12  30  31  32
          TRA-4          1   2   3   4   5   6
          RAD-5
STOP
```

For a complete description of Program RELIB that is beyond the scope of this report, refer to the Mobile Radiometric Laboratory On-Board Data Processing Software, Part II.

As was stated above, two programs must run before RELIB is run; that is, RVAN records raw data in amperes and passes the readings to both RPT and RELIB by either a disk or cassette file. RPT then creates a CAL.DAT file of calibration readings divided into lamp device irradiance data, and passes this file to RELIB.

To reduce this data, the operator specifies which calibration factors are needed for each instrument by specifying an identification number. The program searches file CAL.DAT for the appropriate identification number and stores the calibration factors associated with that number. After the operator has specified all identification numbers for all the instruments, the program averages the calibration factors for each of the instruments and wavelengths, by wavelength. These averages are written to the disk in new files equal to the number of instruments that were operated, and are used to reduce the data to engineering units.

Regardless of whether the data from RVAN is on a cassette or a disk, the program will transfer all the data to a disk file and will perform computations on a new file.

The program reads each header record from RVAN and writes it out on either an output disk file or a second cassette tape depending on whether the program is operating in the cassette mode. If a calibration is encountered, the data record is written out exactly as read. All other data, such as fixed geometry acquisitions (instruments are in fixed position but vary over wavelength) or sky maps (the sky radiometer varies over 92 different instrument azimuths and elevations), are multiplied spectrally by the average calibration factors. After the data is reduced to engineering units, it is written on the output file.

After the program has finished reading all the RVAN data and made all the calculations, there will be two files. One will contain all the raw data in amperes as recorded by RVAN; the second file, configured like the first, will contain all the data converted to engineering units by program RELIB except calibration data, which will still be in amperes. A schematic of these operations is shown in Figure 4-14.

This file created by RELIB is then ready for analysis by software on off-line computers. In general, the data handling for PAR 317S involved transfer of the calibrated data from the single-track cassettes to nine-track tape using a second, off-line Data General system. The nine-track tapes were compatible with the IBM-370 Processor that was used for all analyses of the collected field data. These programs are discussed in Section 7 of Volume 2 of this report.

4.5.2 Format of Data

The two input files for RELIB come from RVAN and RPT (see paragraph 4.3 and 4.4 for discussion of format). The output file from RELIB has the same format as the file from RVAN with a slight modification for sign bit. The data word, which is in engineering units, is formatted as follows:

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

SIGN EXPONENT DATA

(1) If the sign bit is set to 1, the data word is negative; if set to 0, the data word is positive.

(2) The exponent is always negative.

(3) The data word has no implied decimal point.

The calibration acquisition data is in amperes and is left unchanged from input to output.

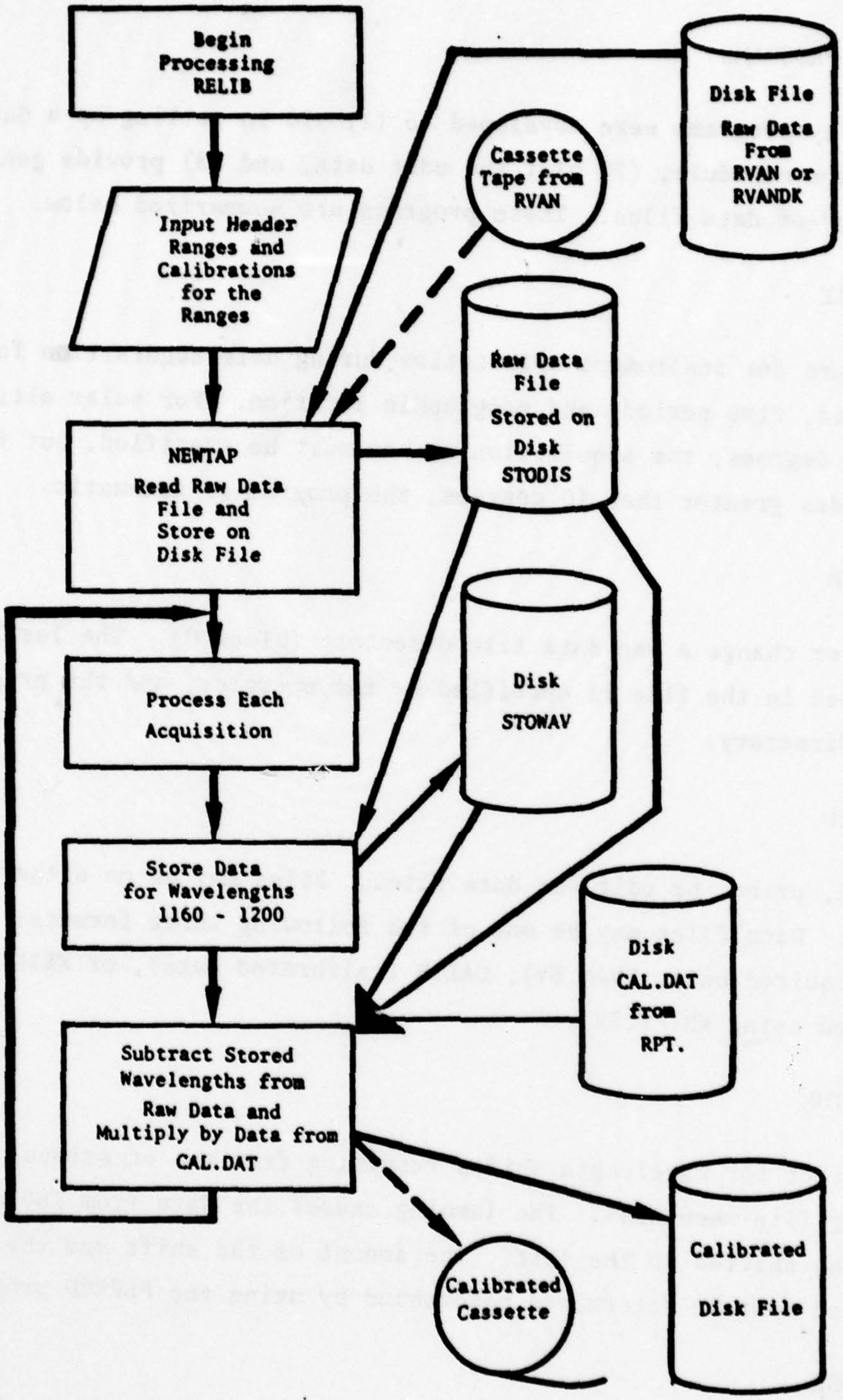

Figure 4-14. Flow Chart of RELIB Program

4.6 UTILITY PROGRAMS

Several utility programs were developed to (1) aid in setting up a daily data collection schedule, (2) plot and edit data, and (3) provide general "housekeeping" of data files. These programs are summarized below.

4.6.1 AQUIDAT

Provides values for instrument orientation during data acquisition for a specified date, time period, and geographic location. For solar altitudes less than 10 degrees, the acquisition number must be specified, but for solar altitudes greater than 10 degrees, the program is automatic.

4.6.2 FIXDIR

Used to fix or change a van data file directory (block 0). The last block to be included in the file is specified by the operator, and the program rewrites the directory.

4.6.3 PLPRED

Used to plot, print, or edit van data files. Files may be on either disk or cassette. Data files may be one of the following three formats: RVAN (Raw data acquired using RVAN.SV), CALIB (calibrated data), or KRIPT (raw data acquired using KRIPT.SV).

4.6.4 SHIFTUM

Used to correct for wavelength shifts resulting from the occasional jamming of a grating flip mechanism. The jamming causes the data from 780 nm to 1200 nm to be shifted to the left. The amount of the shift and the instrument involved must be determined beforehand by using the PLPRED program.

4.6.5 STRDSK

Transfers a van data file (either raw or calibrated) from a cassette tape to the disk. The number of blocks to be transferred must be determined be-

forehand by using the PLPRED program to read the file directory (Block 0). The transferred file must include this directory.

4.6.6 STRTAP

Transfers a van data file (either raw or calibrated) from the disk to a cassette tape. The number of blocks to be transferred must be determined beforehand by using the PLPRED program to read the file directory (Block 0). The transferred file must include this directory.

4.6.6 SUNDAT

Provides a table of time versus solar altitude, solar azimuth, and air masses for a specified date, time period, and geographic location.

Execution of these programs is described in the document Mobile Radiometric Laboratory On-Board Data Processing Software, Part I.

4.7 EXAMPLE OF SPECTRAL DATA

Using the software described in this section, data could be examined in near real-time. This is illustrated in the following example. The option existed to display either raw or calibrated data on the on-board graphics display. This option was exercised for Figure 4-15, which is a hard copy of the screen image for a typical spectral measurement of horizontal daylight irradiance. Table 4-3 is an alternative tabular display of the same data, which was collected on 22 August 1976 at 13:55 GMT and at a solar elevation of 34.23 degrees, as the data header indicates.

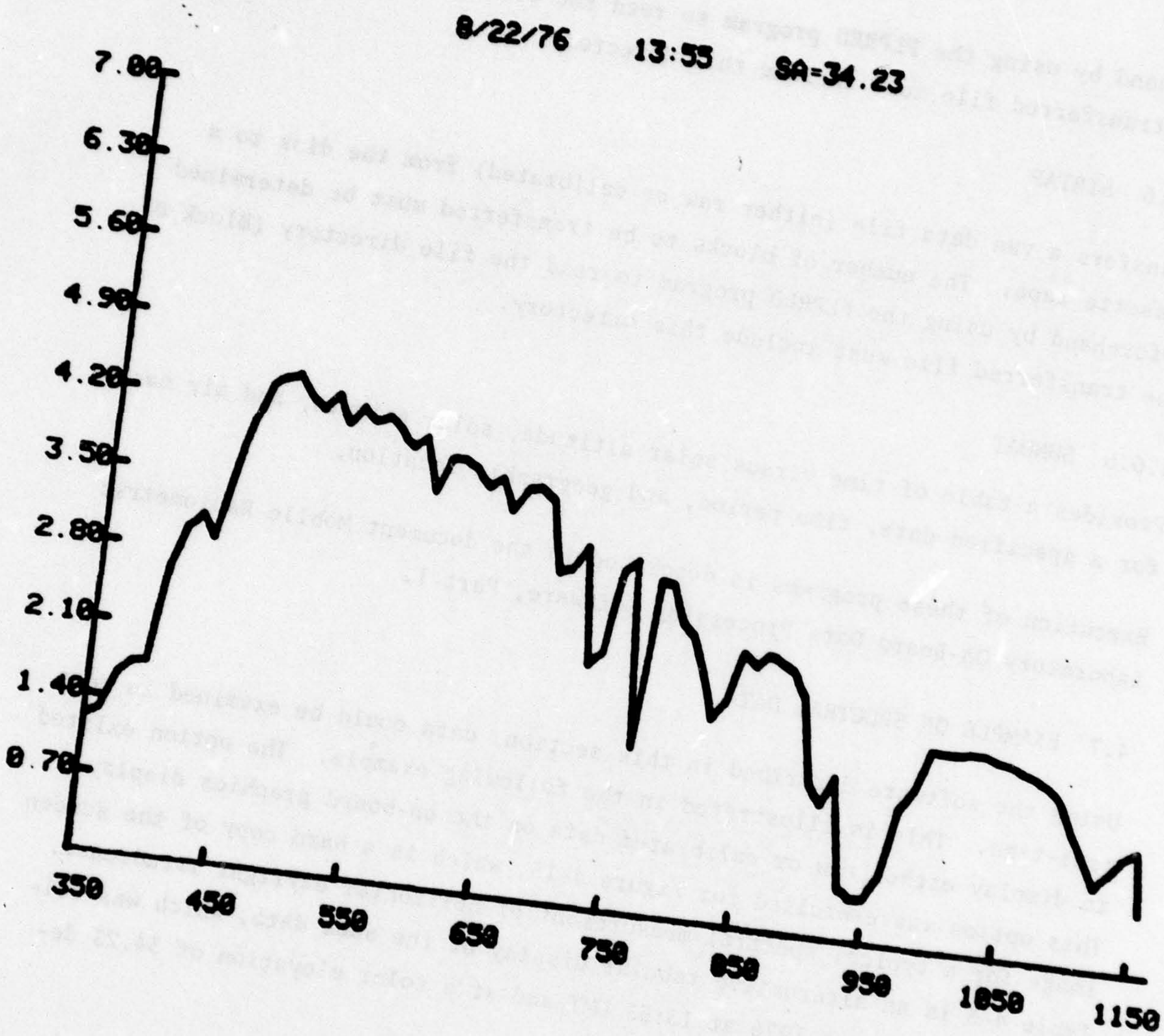

Figure 4-15. Example of Graphics Display Output for a Typical Spectral Sample

TABLE 4-3

EXAMPLE OF GRAPHICS DISPLAY OUTPUT FOR
A TYPICAL SPECTRAL SAMPLE

(List of Figure 4-14 Data)

DATE= 8/22/76 TIME=13:55 SA=34.2[illegible]

350	0.121E	1	0.124E	1	0.128E	1	0.145E	1	0.162E	1
375	0.168E	1	0.173E	1	0.174E	1	0.175E	1	0.220E	1
400	0.264E	1	0.281E	1	0.298E	1	0.304E	1	0.311E	1
425	0.301E	1	0.292E	1	0.322E	1	0.352E	1	0.376E	1
450	0.399E	1	0.416E	1	0.434E	1	0.438E	1	0.441E	1
475	0.443E	1	0.446E	1	0.436E	1	0.427E	1	0.423E	1
500	0.418E	1	0.425E	1	0.432E	1	0.420E	1	0.408E	1
525	0.415E	1	0.423E	1	0.417E	1	0.412E	1	0.415E	1
550	0.418E	1	0.413E	1	0.407E	1	0.408E	1	0.394E	1
575	0.399E	1	0.404E	1	0.381E	1	0.358E	1	0.373E	1
600	0.388E	1	0.389E	1	0.389E	1	0.385E	1	0.382E	1
625	0.374E	1	0.367E	1	0.372E	1	0.376E	1	0.363E	1
650	0.349E	1	0.359E	1	0.369E	1	0.370E	1	0.371E	1
675	0.366E	1	0.362E	1	0.330E	1	0.299E	1	0.301E	1
700	0.303E	1	0.313E	1	0.324E	1	0.272E	1	0.221E	1
725	0.227E	1	0.233E	1	0.270E	1	0.307E	1	0.312E	1
750	0.317E	1	0.234E	1	0.151E	1	0.226E	1	0.301E	1
775	0.300E	1	0.299E	1	0.283E	1	0.267E	1	0.261E	1
800	0.256E	1	0.240E	1	0.224E	1	0.204E	1	0.184E	1
825	0.193E	1	0.202E	1	0.224E	1	0.246E	1	0.241E	1
850	0.236E	1	0.241E	1	0.247E	1	0.244E	1	0.241E	1
875	0.238E	1	0.235E	1	0.224E	1	0.213E	1	0.174E	1
900	0.135E	1	0.127E	1	0.118E	1	0.130E	1	0.143E	1
925	0.942E	0	0.456E	0	0.415E	0	0.374E	0	0.379E	0
950	0.385E	0	0.496E	0	0.608E	0	0.912E	0	0.122E	1
975	0.132E	1	0.142E	1	0.166E	1	0.178E	1	0.178E	1
1000	0.178E	1	0.178E	1	0.178E	1	0.179E	1	0.180E	1
1025	0.180E	1	0.180E	1	0.177E	1	0.176E	1	0.174E	1
1050	0.173E	1	0.171E	1	0.168E	1	0.166E	1	0.164E	1
1075	0.160E	1	0.157E	1	0.152E	1	0.147E	1	0.133E	1
1100	0.119E	1	0.108E	1	0.974E	0	0.853E	0	0.732E	0
1125	0.793E	0	0.855E	0	0.928E	0	0.100E	1	0.104E	1
1150	0.109E	1	0.543E	0						

STOP

APPENDIX A

RELATED SYSTEM DOCUMENTATION AVAILABLE UPON REQUEST

1. Operations and Maintenance Manuals for the Mobile Radiometric Measurement Systems

   Vol 1: Optical

   Vol 2: Software (KRIPT)

   Vol 3: Electrical

   Vol 4: Weather System

   Vol 5: Mechanical

   Vol 6: Radiometric Analysis of Instruments

2. Mobile Radiometric Laboratory: System Description

3. Mobile Radiometric Measurements System Data Acquisition Software: RVAN

   Part I: Operator's Manual

   Part II: Software Description

4. Mobile Radiometric Laboratory On-Board Data Processing Software

   Part I: Utility Software Operation

   Part II: Calibration Software

5. Instrument Calibration for the Radiometric Van

APPENDIX B

LIMB DARKENING CORRECTION FACTOR (LDCF)

Use of the LDCF

Atmospheric transmittance is estimated by dividing the solar irradiance at the ground by the published solar irradiance above the earth's atmosphere. In the Mobile Radiometric Laboratory, the solar irradiance at the ground is measured by the transmissometer aimed at the center of the solar disk. The transmissometer aperture allows the radiation from 0.4 diameter of the solar disc to fall on the sensor.

The measured central disk radiance, as defined by the input optics and the sampling aperture size, is greater than that from any other portion of the disk. Thus, the measured radiance must be corrected to a mean disk radiance by a factor known as the Limb Darkening Correction Factor which is used in calculating atmospheric transmittance as defined in paragraph 3.1.3 of this report.

Because the sun is spherical and radiates equally in all directions, its radiation intensity in the direction of the earth is far greater at the center of the solar disc than at its edge. This phenomenon, called limb darkening, is the result of the radiation intensity being a function of the cosine of the angle between the radiating direction and the radiating surface normal (see Figure B-1). In addition to decreasing the brightness toward the limb, it has been found that this decrease is more pronounced for the shorter wavelengths. The ratio of the earthbound radiance at any point on the solar disc to that at the center of the solar disc (normal to the sun's surface) is called the directional radiance ratio (DRR) and is defined mathematically as follows:

$$DRR_\lambda = \frac{N_{s_{\Theta_\lambda}}}{N_{s_\lambda}} \qquad \text{(B-1)}$$

Where: DRR_λ is the direction intensity ratio,

$N_{s_{\theta_\lambda}}$ is the earthbound radiance from any point on the solar disc, and

N_{s_λ} is the earthbound radiance from the center of the solar disc.

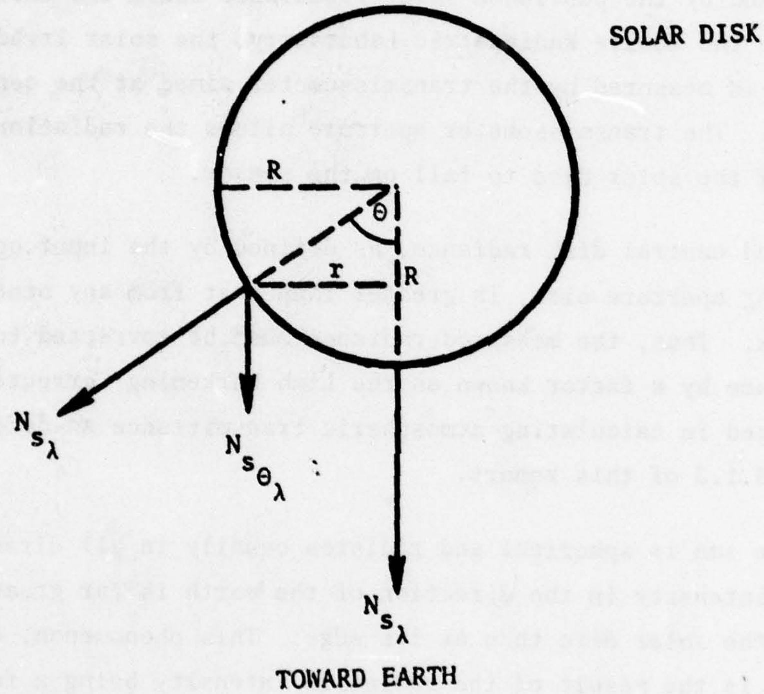

Figure B-1. Solar Disk Radiance Directed Toward Earth as a Function of the Disk Fraction

The LDCF is the ratio of the average solar irradiance from the measured portion of the solar disc to that of the whole solar disc. It can also be defined as the ratio of the average earthbound radiances from the corresponding portions of the sun, or

$$LDCF_\lambda = \frac{\bar{N}_{M_\lambda}}{N_{s_\lambda}} \qquad \text{(B-2)}$$

Where: $\bar{N}_{M_\lambda}$ is the average earthbound radiance from the measured portion of the solar disc, and

$\bar{N}_{s_\lambda}$ is the average earthbound radiance from the entire solar disc.

Defining the LDCF

The first step in determining the LDCF was to plot published* Directional Radiance Ratios (DRRs) as a function of wavelength and the solar disc fraction (f) shown in Figure B-2. This ratio is defined as $N_{s_{\theta_\lambda}}/N_{s_\lambda}$, the ratio of earthbound radiant intensity at the disc center (f = 0) to that for any disk fraction.

The DDR at any point on the solar disc can be considered to be a three-dimensional plot for each wavelength as shown in Figure B-3. The average radiance of any disc fraction was then computed as the average height of the function within that disc fraction multiplied by the radiance at the disc center. Using equations B-1 and B-2 above, the values of LDCF were computed as follows:

$$LDCF_\lambda = \frac{\bar{N}_{M_\lambda}}{\bar{N}_{s_\lambda}} = \frac{N_{s_\lambda} \int_0^f DDR_\lambda df/\pi f^2}{N_{s_\lambda} \int_0^1 DDR_\lambda df/\pi} \qquad \text{B-3}$$

Simplifying,

$$LDCF_\lambda = \frac{\int_0^f DDR_\lambda df}{f^2 \int_0^1 DDR_\lambda df} \qquad \text{B-4}$$

Values for the above integrals were generated for f ratios of from 0 to 1 at wavelengths from 300 to 1200 nanometers. The LDCF values computed at

* The Sun, edited by Gerard P. Kuiper, University of Chicago Press, 1953, Chapter 3.

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SPECTRAL RADIOMETRIC MEASUREMENT AND ANALYSIS PROGRAM. VOLUME 1--ETC(U)
APR 79 L G CHRISTENSEN, R SIMMONS, G SCHAUSS

UNCLASSIFIED   AWS-TN-79/001-VOL-1   NL

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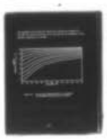

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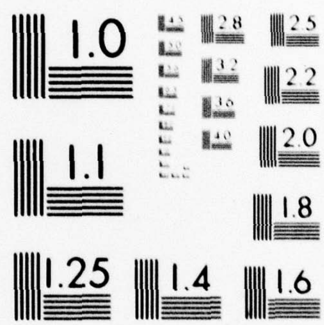

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

100 nanometers are plotted for various disc fractions in Figure B-4. The LDCF for the disc fraction of 0.4 was used for the atmospheric transmittance computation in the MRL.

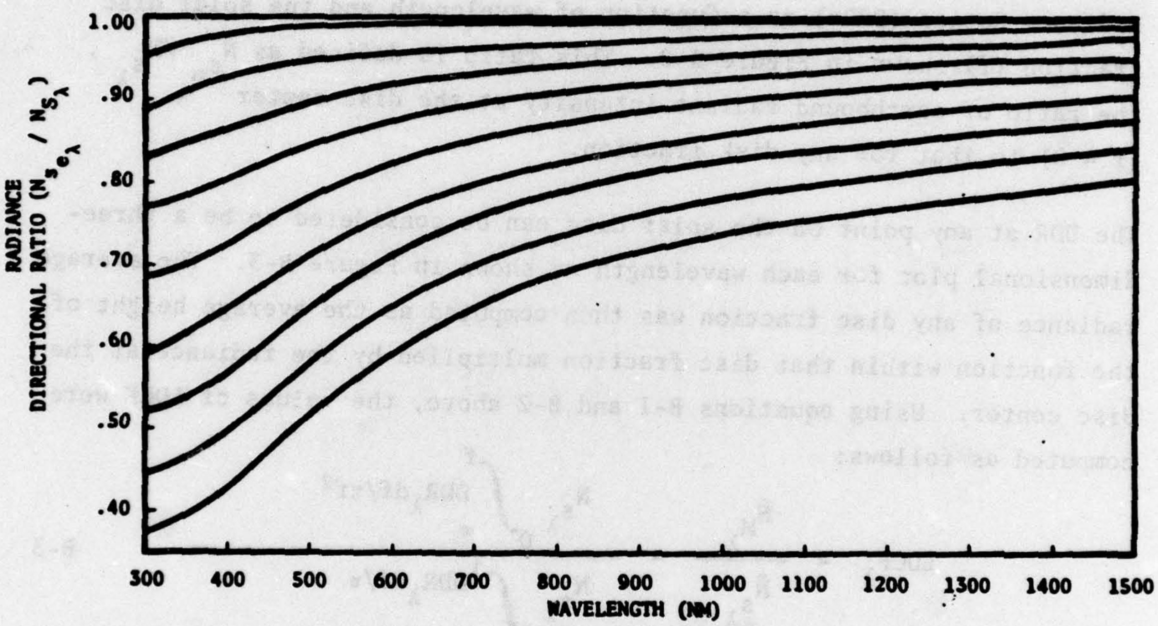

Figure B-2. Directional Radiance Ratio as a Function of Wavelength and Solar Disc Fraction

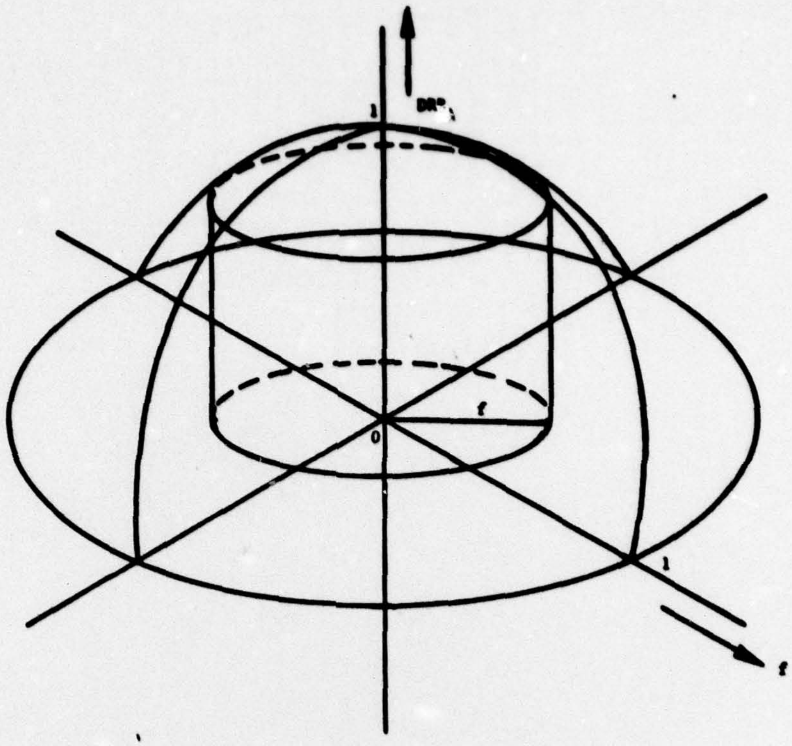

Figure B-3. Illustration of Directional Radiance Ratios as a Function of Disc Fraction

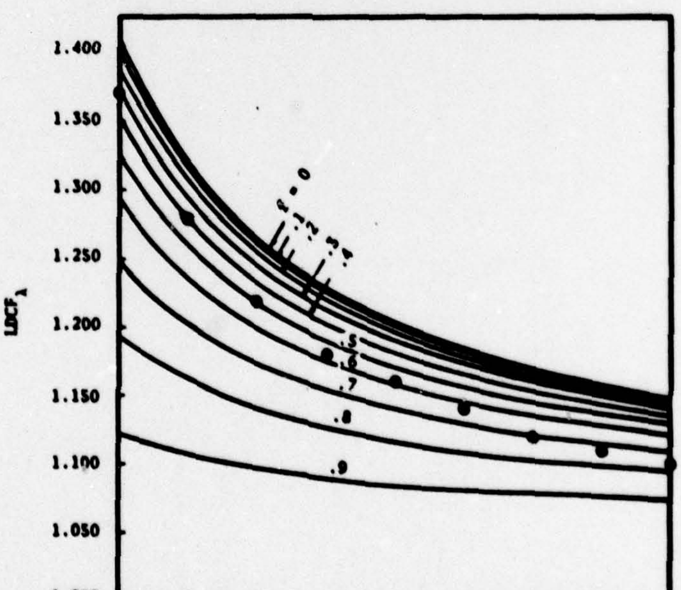

Figure B-4. LDCF as a Function of Wavelength and Disc Fraction